REPORT

Capacity building on decision support for air pollution policies – results from Nordic-Russian co-operation

Final report to NMR

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Report Summary

Project title

Capacity building regarding data inventory and air pollution modelling with the EMEP and GAINS models - applied on Oblasts of the Russian Federation

Project sponsors

Nordic Council of Ministers
Swedish Clean Air Research Programme, the Swedish Environmental Protection Agency

Authors

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Title and subtitle of the report

Capacity building on decision support for air pollution policies
– results from Nordic-Russian co-operation

Summary

In 2010 the Nordic Council of Ministers initiated a research project with the aims to enable capacity building on the EMEP/MSC-W model, expand data inventories in the Russian Federation, and to develop a Russian version of the GAINS model.

The project activities were: Identification of regions to be modelled; EMEP/MSC-W model calculations and capacity building; GAINS model development and adaptation; Emissions & Data inventories and consistency checks; GAINS model scenario analysis.

The project resulted in an updated GAINS Russia model, regionalised and sector-specific emission inventories, region-specific source-receptor calculations, and EMEP/MSC-W model training activities. Finally, regionalised emission abatement scenarios were analysed and showed large differences between regions in terms of potential emission reductions and emission abatement costs.

The Russian Federation has now established analytical capacity related to the GAINS and EMEP/MSC-W models, the GAINS Russia model has been updated and improved, and a process for preparing input data inventories has been initiated. The Russian Federation can now launch independent research on cost effective emission reductions in the Russian Federation and analyse consequences on human health and the environment.

Keyword

CLRTAP, Air Pollution, Integrated Assessment Modelling, EMEP/MSC-W modelling

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Summary

This is the final report of the project *Capacity building regarding data inventory and air pollution modelling with the EMEP and GAINS models – applied on Oblasts of the Russian Federation*, financed by the Nordic Council of Ministers (project KOL 10-11) and co-financed by the Swedish Clean Air Research Programme (SCARP).

In 2008 Finnish-Swedish-Russian co-operation research activities were initiated with the purpose of increasing the Russian engagement in the United Nations Economic Commission for Europe Convention on Long Range Transboundary Air Pollution. These research activities focused on capacity building on GAINS modelling, an important decision support model used in negotiations aimed at controlling air emissions of primarily sulphur dioxides, nitrogen oxides, ammonia, non-methane volatile organic compounds, and fine particulate matter. However, during this work it was identified that the most commonly used version of the GAINS model did not represent Russia at a suitable level of detail for Russian purposes. A need for knowledge on the EMEP/MSC-W model was thus also identified. Responding to these needs, the Nordic Council of Ministers decided in 2010 to complement the Finnish-Swedish-Russian co-operation research activities with this research project, with the purpose to enable further capacity building on the EMEP/MSC-W model, expand data inventories in the Russian Federation, and develop a Russian version of the GAINS model.

The activities in this project were performed by partners from IVL Swedish Environmental Research Institute (project coordinator), the Finnish Environment Institute (SYKE), Meteorologisk Institutt (MET Norway), Metropolia, the International Institute for Applied System Analysis (IIASA), and the Scientific Research Institute for Atmospheric Air Protection (SRI Atmosphere).

The project was divided into five main research activities:

1. Identification/selection of the Russian regions to be modelled
2. EMEP/MSC-W model calculations and capacity building
3. GAINS model development and adaptation
4. Emissions & Data inventories and consistency checks
5. GAINS model scenario analysis

The project activities resulted in an updated GAINS Russia model including 9 regions, out of which 8 correspond to administrative units in the Russian Federation and 1 region corresponds to the Larger Moscow region. Regionalised and sector-specific emission inventories were constructed for the regions and used as a basis for EMEP/MSC-W model calculations. Following this, source-receptor calculations were performed for those regions in order to provide necessary input to the GAINS Russia model. Furthermore, EMEP/MSC-W model training activities were performed to build capacity in the Russian Federation. Finally, regionalised emission abatement scenarios were analysed revealing large

differences between regions in terms of emission reduction potentials and emission abatement costs.

After the finalisation of this project, and with contributions from the Swedish-Finnish-Russian co-operation project, the Russian Federation now has established analytical capacity related to the GAINS and EMEP/MSC-W models. Also, the GAINS Russia model has been updated and improved, and input data inventories are initialised. The Russian Federation can now launch independent research on cost effective emission reductions in the Russian Federation and analyse consequences on human health and the environment from reduced emissions of air pollutants in Russian regions. The analytical approach can in the future be further developed to include aspects such as ozone damages, and effects on radiative forcing due to short lived climate pollutants, but also air pollution aspects of different energy scenarios for the Russian Federation. These results can serve as a motivation for both an enhanced co-operation between regional authorities and federal authorities in the Russian Federation as well as increased international co-operation between the Russian Federation and other countries.

Contents

Glossary

ArcView GIS	Geographical information system software
CCS	Carbon capture and storage
CEIP	Centre on emission inventories and projections
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CO	Carbon monoxide
ECMWD-IFS	European Centre for Medium-Range Weather Forecasts - Integrated Forecasts
EECCA	Eastern Europe, Caucasus and Central Asia
EMEP	European Monitoring and Evaluation Programme
FD	Federal district
Fortran	Programming language especially suited to numeric computation and scientific
GAINS	Greenhouse Gas – Air Pollution Interactions and Synergies
HIRLAM	High Resolution Limited Area Model (weather prediction model)
IEA	International Energy Agency
IIASA	International Institute for Applied System Analysis
MET Norway	Norwegian Meteorological Institute
MSC-W	Meteorological Synthesizing Centre - West
NH_3	Ammonia
NOx	Nitrogen oxides
Oblast	Russian administrative region, corresponding relatively well to a western European
Okrug	Russian administrative region (larger than oblast), often corresponding to a federal
PARLAM-PS	Numerical weather prediction model
PM_{10}	Particulate matter**,** 10 microns in diameter or smaller
$PM_{2.5}$	Particulate matter, 2.5 microns in diameter or smaller
$PPM_{2.5}$	Primary particulate matter**,** 2.5 microns in diameter or smaller
RAINS	Regional Air Pollution Information and Simulation
Rosstat	Information and publishing center “Statistics of Russia”
SIA	Secondary inorganic aerosols
SNAP	Selective Nomenclature for Air Pollution
SO_2 / SO_x	Sulphur dioxide / Sulphur oxides
SR	Source-receptor
SRI Atmosphere	JSC “Scientific Research Institute for Atmospheric Air Protection”
SYKE	Finnish Environment Institute
TFIAM	Task Force on Integrated Assessment Modelling
UNECE	United Nations Economic Commission for Europe
VOC	Volatile organic compounds
New GAINS Russia Regions	
CFD	Central Federal District excluding Larger Moscow region
CFM	Central Federal District including Larger Moscow region
LMD	Larger Moscow region
NCD	North-Caucasian Federal District
NWFD	North-Western Federal District
SFD	Southern Federal District
VFD	Volga Federal District

1 Introduction

Development of the European air policy under the Convention on Long Range Transboundary Air Pollution (CLRTAP) is performed with an intensive communication between scientists and decision makers as an important ingredient. Due to the transboundary and multi-effect nature of air pollution and air pollution control, models have become important decision support tools. Due to this, much effort is needed of decision makers in order to understand and interpret model results. This in turn requires active engagement in the process, but this engagement is since many years absent in several European countries. This absence inhibits their possibility to understand and interpret model results, and thereby participate actively in negotiations. Participation of all European countries in the CLRTAP negotiations is important for the continued improvement of the European and Nordic environment.

1.1 Project history and problem description

In 2008, based on the results from the international air pollution workshop "Saltsjöbaden III" (Grennfelt et al., 2007), a co-operation project involving IVL Swedish Environmental Research Institute (IVL), the Finnish Environment Institute (SYKE), and the Scientific Research Institute for Atmospheric Air Protection (SRI Atmosphere) from Russia, was launched with the aim to support Russian research activities related to the on-going negotiations in the CLRTAP. The project activities focused on the collection and evaluation of data on region-specific economic activities causing emissions as well as Russian application of the Greenhouse Gas – Air Pollution Interactions and Synergies (GAINS) model. Within the project, a fruitful working environment was established between Swedish, Finnish, and Russian experts, as well as the International Institute of Applied System Analysis (IIASA).

The integrated assessment model GAINS, and the European Monitoring and Evaluation Programme (EMEP) model are used by the CLRTAP to simulate the impact on the environment from air pollutants and control strategies, as well as economic costs to fulfil the environmental quality targets (Amann, 2012; Simpson et al., 2012).

During the co-operation project it was recognised that the existing version of the GAINS Europe was set up to only perform calculations for the European part of Russia as one aggregated region, not distinguishing different administrative (regional) divisions. Also, in the existing GAINS Russia model it was not possible to calculate environmental impacts from emission reductions. Thus, for 24 regions of the Russian Federation included in the GAINS Russia model it was not possible to perform calculations of transboundary pollution or impact analysis. To do so, emission dispersion patterns and descriptions of ecological sensitivity were needed. Furthermore, the regional division in the GAINS Russia did not fully correspond to the regional administrative division of the Russian Federation which created obstacles in the collection of activity data and comparison of model results with emission inventories. Within the earlier mentioned project, activity data were collected for two of the GAINS Russia regions. Later it was recognized as necessary to re-adjust regions in the GAINS Russia model so that they would correspond to the current administrative division of the Russian Federation.

In order to reach a fully functional GAINS model applied to the Russian Federation, it was necessary to complement the existing Nordic-Russian collaboration activities with other scientific tasks than GAINS modelling. In particular, activity data inventories, calculation of emissions and updated calculations of air pollution dispersion i.e. atmospheric modelling using the EMEP/MSC-W model were needed. Since existing estimates for the Russian regions in the GAINS model were uncertain, mainly due to a low degree of participation from the Russian Federation, it was also important to expand the activities aimed at activity data inventory and projections for a larger number of Russian regions than covered in the previously mentioned project.

1.2 Nature, scope, and aim with the project

In 2010, this new collaboration project, "Capacity building regarding data inventory and air pollution modelling with the European Monitoring and Evaluation Programme (EMEP) and GAINS models – applied on Oblasts of the Russian Federation", started. The purpose of the project was to establish knowledge and capacity to aid Russia's work within the CLRTAP. The specific project aims were to use Nordic expertise to establish Russian knowledge in the air pollution chemical transport and source-receptor calculations using the EMEP/MSC-W model, to develop a functional Russian version of the GAINS model, and to communicate project results at international forums. The project expanded earlier collaboration activities by additional capacity building and by networking activities. The activities aimed to increase the capacity in Russia to, in addition to GAINS modelling, also cover air pollution dispersion and source-receptor modelling and improving activity data inventory as well as development of projections for Russian regions. These collaboration activities have been financed by the Nordic Council of Ministers and the Swedish Environmental Protection Agency through the research programme Swedish Clean Air Research Programme (SCARP).

1.3 Nordic advantage

This project has several potential advantages for the Nordic countries. With established Russian expertise, and thereby improved activity data provided by Russian experts, more accurate GAINS modelling and atmospheric modelling can be performed. This will allow a more detailed analysis of cost effective European emission reduction strategies with the GAINS model. This in turn will influence the development of National and European air pollution policies, especially for the Nordic countries, due to their geographical location as neighbours to Russia.

The project could, through the established capacity of Russian experts, in the long run benefit the environment in the Nordic countries. In 2010, the Russian Federation contributed with 2, 22, 3, and 8% of the sulphur deposition in Denmark, Finland, Norway and Sweden respectively. The corresponding numbers for oxidised nitrogen were 12, 32, 13, and 16%, and for reduced nitrogen 3, 16, 3, and 6% (EMEP, 2012), respectively. These shares are likely to increase as EU countries continue to decrease their emissions if Russia does not. A Russian adoption of the targets set in the latest protocols of the CLRTAP will hopefully decrease emissions in Russia, which in turn will reduce transboundary transport and deposition of air pollutants in the Nordic countries. This will provide a substantial contribution in the Nordic work of reaching air quality and environmental targets.

The project has developed the Nordic collaboration with Russia in environmental affairs and has strengthened the Nordic position as an important party for the successful implementation and ratification of the CLRTAP protocols. An established modelling and data knowledge in Russia and at SRI Atmosphere will hopefully result in increased Russian engagement in the work of the CLRTAP. This will set the necessary scientific arena for a future Russian ratification of the CLRTAP protocols. Furthermore, increased Russian participation in the protocols is important for increased CLRTAP participation of other EECCA countries.

1.4 Project participants

The project includes participants from IVL Swedish Environmental Research Institute, Finnish Environment Institute (SYKE), Metorologisk institutt (MET Norway), Metropolia, the International Institute for Applied Systems Analysis (IIASA), and the Scientific Research Institute for Atmospheric Air Protection (SRI Atmosphere).

IVL is an independent research body that has been involved since 1966 in the development of solutions to environmental problems on behalf of the business sector and the community. For a long time, IVL has been involved in the development of the CLRTAP. IVL functioned mainly as project coordinator in this project.

SRI Atmosphere is the leading Russian institute responsible for atmospheric air protection. SRI Atmosphere responsibilities lie in terms of scientific, methodological and expertise support to a wide range of stakeholders from environmental practitioners to local and federal authorities. In this project SRI Atmosphere participated with activity data inventory, EMEP/MSC-W modelling and emission analysis.

MET Norway is the host of the CLRTAP Meteorological Synthesizing Centre - West since the beginning of the EMEP programme in 1979. A key product of the MSC-W modelling work within EMEP is the source-receptor matrices that estimate the contribution of the emissions in any country to the deposition or air concentration of main pollutants, ground level ozone and fine particulate matter in any other country. In this project the main task of MET Norway was to model transboundary fluxes of air pollutants with the EMEP/MSC-W model.

The expertise from the Helsinki University of Applied Sciences, Metropolia, is based on long-term environmental monitoring, wide-ranging research results, and the University's highly qualified staff. In this project Metropolia provided an overview of available sources of relevant national data and a methodology for data transformation into the GAINS format.

IIASA is an international research organization that conducts policy-oriented research on problems that are too large or too complex to be solved by a single country or academic discipline. Research activities involve for example areas such as climate, air pollution, forestry etc. IIASA's input into the project was an adjustment of the GAINS Russia model by introduction of the new regionalization and a technical possibility to calculate trans-boundary fluxes between regions.

This report presents the scientific methodology and results achieved in this project.

2 Methodology

This chapter gives an introduction to the EMEP/MSC-W and GAINS modelling concepts and a detailed description of the input data and method used to perform each of the analytical tasks in this project.

Overall, the project activities consisted of five main activities with several tasks:

1. Regionalisation of the EMEP/MSC-W chemical transport model and the GAINS Russia model for the Russian territory
2. EMEP/MSC-W model source-receptor calculation
    a. Open-source EMEP/MSC-W modelling used to soft-link source-receptor calculations with emission calculations in the GAINS Europe model
    b. EMEP/MSC-W modelling on Russian regions necessary for updating the GAINS Russia model
3. GAINS Russia model adaptation
    a. Update of chemical transport calculations using EMEP/MSC-W model results
    b. Update of GAINS Russia model features
        i. Activation of environmental impact analysis feature
        ii. Activation of control cost calculation feature
        iii. Regional disaggregation of Russian emission precursor data[1] from European scenarios.
4. Emission precursor data inventory and consistency checks
5. GAINS Europe & Russia scenario analysis

[1] Emission precursor data include inter alia activity data on fuel combustion, production in industry, transport demand, as well as data on agricultural activities such as live-stock numbers and application of manure.

As an overview, in Activity 1, the 24 original regions in the old version of GAINS Russia were aggregated into nine larger regions, out of which six covered Europe. For the six regions covering Europe, the following activities were performed:

- Source-receptor dependencies were calculated with the EMEP/MSC-W model (Act. 2);
- Regions, impact, and control cost feature were introduced into the GAINS Russia model (Act. 3);
- Emission precursor data were collected and transformed into the GAINS Russia format (Act. 4);
- Scenarios on emissions, environmental impacts, and emission control costs were calculated and analysed (Act. 5).

In addition to these main tasks, other tasks, based on the GAINS Europe model and the open source EMEP/MSC-W model were performed as well. Several test runs with the open-source EMEP/MSC-W model were performed to analyse the source-receptor dependencies between six subject regions in the North-West Federal District of the Russian Federation that are represented in the GAINS Europe model. For these, source-receptor (blame) matrices were calculated (Act. 2). The results of the EMEP/MSC-W modelling at the oblast level were used to soft-link the GAINS Europe results with detailed EMEP/MSC-W model source-receptor calculations (Act. 5). The methodology and the results of these calculations are included in this report.

2.1 Model descriptions

The two models used in the project were the EMEP/MSC-W model and the GAINS model. Both models are constantly updated and exist in several versions, but the description given below is valid for the model versions used in this project.

2.1.1 The EMEP/MSC-W model

The EMEP/MSC-W model is a multi-layer chemical transport model designed for simulating the long-range transport of air pollution over Europe (Simpson et al., 2012). The model is developed at the Meteorological Synthesizing Centre – West of EMEP hosted by MET Norway.

One of the main outputs of the EMEP/MSC-W model are air concentration fields of ground level ozone (O_3) and Particulate Matter (PM_{10} and $PM_{2.5}$) and deposition fields for acidifying and eutrophying compounds (oxidised sulphur and oxidised and reduced nitrogen).

For these pollutants, fluxes across national boundaries and source-receptor relationships are also calculated. The standard emissions input required by the EMEP/MSC-W model consists of gridded annual national emissions of sulphur dioxide (SO_2), nitrogen oxides (NO_x =NO+NO_2), ammonia (NH_3), non-methane volatile organic compounds (NMVOC), carbon monoxide (CO), and particulates ($PM_{2.5}$, PM_{10}). The chemical transport model runs are driven by a set of meteorological fields.

The standard EMEP/MSC-W model used in this project operates with a polar stereographic projection true at 60ºN with a grid size of 50x50 km^2 covering all of Europe and extending vertically from ground level to the tropopause.

The EMEP/MSC-W model has been adapted to run with meteorological fields from a number of numerical weather prediction models, including PARLAM-PS (Lenschow and Tsyro, 2000; Bjørge and Skalin, 1995; Benedictow, 2003), HIRLAM version 7.1.3 (Unden et al., 2002) and ECMWF-IFS Cycle36r1 (ECMWF, 2004; 2010a,b,c,d,e,f). Since 2011 ECMWF-IFS is used as the standard meteorological driver for the EMEP/MSC-W model.

The open source EMEP/MSC-W model with all necessary input data as well as the history of the model development is available on the internet address: http://www.emep.int.

2.1.2 The GAINS model

The GAINS model can be used to explore synergies and trade-offs between the control of local and regional air pollution and the control of global greenhouse gas emissions (Amann et al., 2011; Amann, 2012; Amann et al., 2008; Borken-Kleefeld et al., 2009; Böttcher et al., 2008; Cofala et al., 2008; Höglund-Isaksson et al., 2008). The GAINS model is the extension of the Regional Air Pollution Information and Simulation (RAINS) model developed by IIASA as a tool for the integrated assessment of alternative strategies to reduce acid deposition in Europe and Asia (Amann et al., 2004). The model estimates emissions, control potentials and control costs for the air pollutants SO_2, NO_x, PM, NH_3, NMVOC and for the six greenhouse gases (GHG:s) included in the Kyoto Protocol. As mentioned, there are several different versions of the model. Of interest for this project are the GAINS Europe and the GAINS Russia model.

GAINS Europe covers 43 countries in Europe including the European part of Russia and is available on the internet address: http://gains.iiasa.ac.at/models/index.html.

GAINS Russia covers the whole territory of the Russian Federation, divided into several regions, and is currently available for project participants.

2.2 Regionalization and emission inventory

The GAINS Russia geographical division and activity data sets were first developed by IIASA in co-operation with a Russian expert in 2002 (Popov, 2002). The regional split included 24 regions (see Figure 1 and Appendix 1). The regions were consistent with the administrative division of the Russian Federation in 2002, i.e. each of the regions covered one or several federal subjects (administrative units). Federal subjects of the Russian Federation are divided into several categories having different legal status. The most usual subject category is oblast.

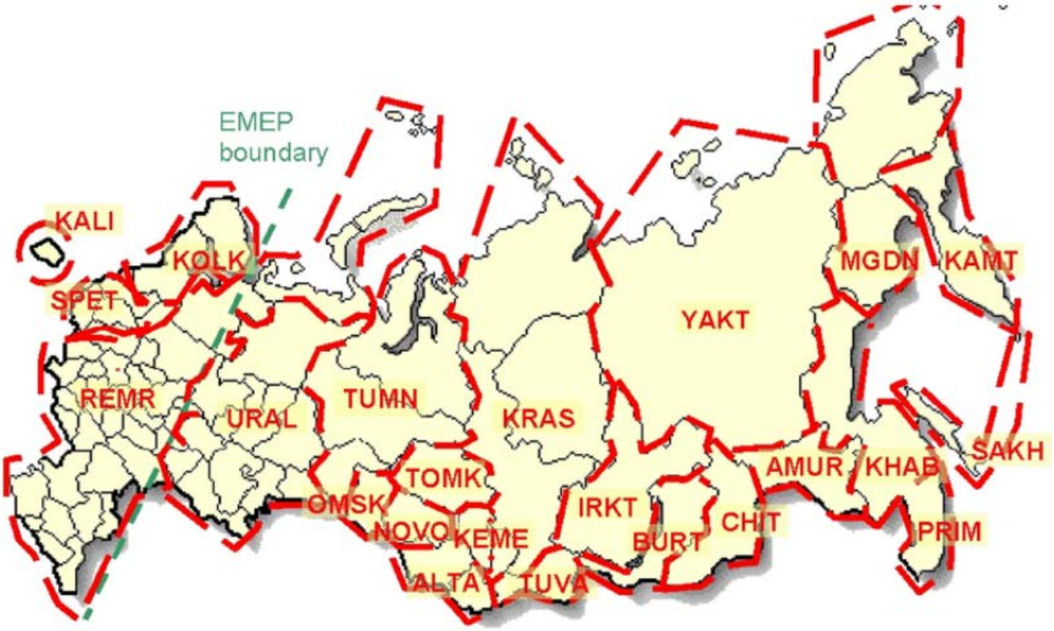

Figure 1: Regions in the original GAINS Russia module (Popov, 2002)

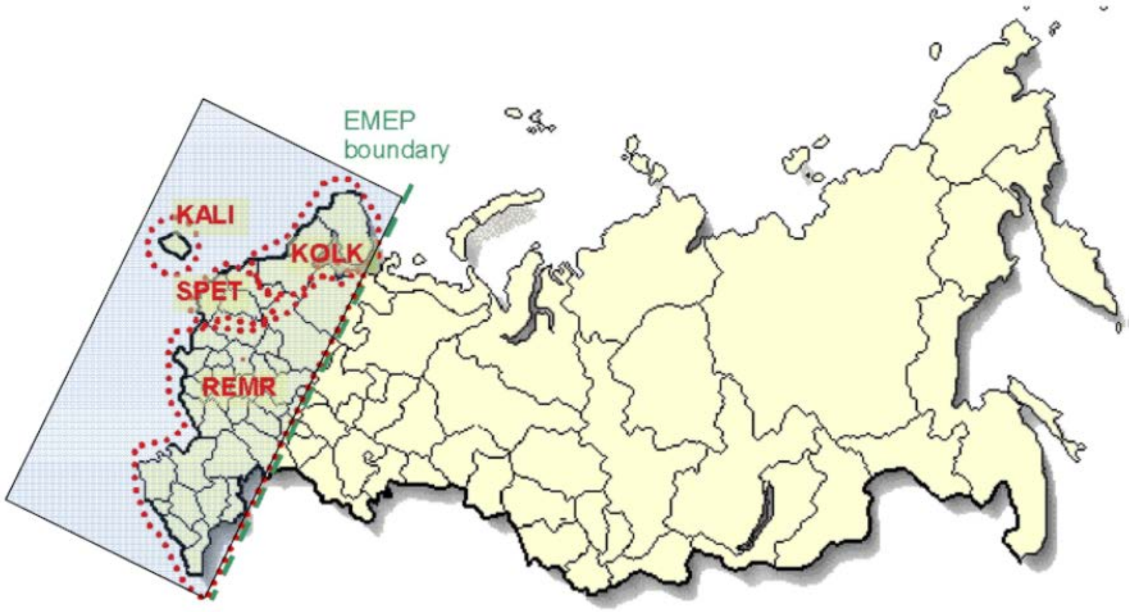

Figure 2: EMEP boundary on the territory of the Russian Federation (Popov, 2002)

In the earlier version of the GAINS Europe, four European regions of Russia were represented (see Figure 2). Emission dispersion from these regions was, as presented earlier, represented by one emission transfer matrix in the GAINS model, shown in the figure by the grey area.

The administrative division of the Russian Federation has changed since 2002. The administrative regions of the Russian Federation have merged and split, so the earlier GAINS Russia regions were no longer consistent with the administrative division in 2011. Following the changes in administrative regions it was decided to disaggregate the GAINS Russia model into new regions, more consistent with the current administrative regions.

The following GAINS Russia regions were considered as most relevant:

1. Central Federal District (excluding Larger Moscow region)
2. Southern Federal District
3. North-Western Federal District (covering Kola and Karelia, Kaliningrad, Sankt Petersburg and other North-Western regions shown in Figure 3 below)
4. Volga Federal District
5. North Caucasian Federal District
6. Larger Moscow region (administrative district including city of Moscow and Moskovskaya oblast).
7. Ural Federal District
8. Siberian Federal District
9. Far East Federal District

The main principle of this division was consistency with actual large geographical formations of administrative units in the Russian Federation – federal districts. Each region covers one federal district (except for the Larger Moscow region and the Central Federal District, each covering a part of the Central Federal District). The administrative structure and the current number of subjects of the Russian Federation are quite changeable. However, merging and splitting of subjects usually occurs within one federal district rather than between federal districts. Therefore, eventual future changes in the administrative structure of the Russian Federation would hardly affect the suggested regional division and resulting emissions in the GAINS Russia regions. Statistical data are available on both subject and federal district levels, so this level of regionalization was estimated as suitable for collection of emission precursor data as well.

Another argument for a model regionalisation of Russia into federal districts was the already existing regions used by IIASA in the GAINS World model (see Figure 3). GAINS World is already regionalised according to the geographical boundaries of federal districts of the Russian Federation, with the exception of the North-Western Federal District. The North-Western Federal District is covered by four GAINS World regions. By basing the regionalisation in this project on the GAINS World regionalization no additional re-structuring needed to be done except for merging the four separate regions into one North-Western Federal District in GAINS Russia.

The Larger Moscow region was chosen as a separate region in the GAINS Russia in order to allow for illustration of the health impacts in the city region caused by high levels of PM emissions (significantly from transport sources). This region consists of the city of Moscow and Moskovskaya oblasts (area around the city) that are two different administrative units.

Figure 3: Russian regions in the GAINS World model

2.3 EMEP/MSC-W model source-receptor calculations

In order to do accurate source-receptor matrices between the regions, it is necessary that data on emissions are of high quality; both as totals for each regions, but also separated into SNAP sectors. Moreover, the spatial distribution of emissions within a region is important, as emissions close to the border of another region can contribute more to the bordering region than do emissions located at the centre of the considered region.

A common output of the EMEP/MSC-W modelling is a computation of so called "blame matrices", showing pollution from each of the countries/regions/districts to all other countries/regions/districts (or the pollution in each of the districts due to emissions in the other districts). During the project, blame matrices were calculated on both subject level and federal district level.

The EMEP/MSC-W modelling within this project was performed with both the extended and non-extended EMEP grid domains (Appendix 2). The non-extended EMEP grid only covers the European part of the Russian Federation. The extended EMEP grid version of the EMEP/MSC-W model, first presented in 2008, covers almost the whole area of the Russian Federation except some areas of the Far East Federal District.

After data collection of grid- and sector-specific emissions, the extended-grid EMEP/MSC-W model was used to calculate emission dispersion patterns from each of the selected regions for the Russian Federation. The calculated air concentration and deposition fields due to emissions of the regions were then used as basis for the calculations of transfer matrices in the updated version of the GAINS Russia model. Additional source-receptor modelling was also performed for selected Russian oblasts with the non-extended EMEP/MSC-W model. The purpose with this modelling was to analyse transboundary emission fluxes between certain Russian administrative regions and neighbouring countries.

2.3.1 EMEP/MSC-W modelling with non-extended grid for soft-linking with the GAINS Europe model

Detailed emission source-receptor modelling with the non-extended grid version of the EMEP/MSC-W model was performed on a subject level and a federal district level. The calculated results also included nine neighbouring countries since emissions from western subjects of the Russian Federation often disperse into other European countries and vice versa. The following modelling was performed on subject and federal district levels.

Subject level

Source-receptor modelling with the EMEP/MSC-W model on subject level included the following:

1 Calculation of emission transfer between two of the GAINS Europe regions – SPET and KOLK – and the rest of Europe in 2005. For that task, scenarios were developed with and without emission control for each of the two considered regions. NO_x and SO_2 emissions calculated in the GAINS Europe model were used as input to the EMEP/MSC-W model, which calculated the related deposition of sulphur and oxidised nitrogen in SPET, KOLK and in the neighbouring regions. Transboundary fluxes between the regions were then derived by summing up the calculated deposition.

2 Developing blame matrices for NO_x and SO_2. For this task, data from the UNECE CLRTAP Centre for Emission Inventories and Projections (CEIP) were used for the year 2008 for European countries and the results of the national emission inventory were used for Russian regions (total emissions by administrative subjects). Blame matrices included eight subjects of the Russian Federation (Leningrad (LENI), Murmansk (MURM), Arkhangelsk (ARKH), Novgorod (NOVG), Pskov (PSKO), Vologda (VOLO), Kaliningrad (KALI), and Republic of Karelia (KARE)) and ten nearby countries (Estonia (EE), Poland (PL), Germany (DE), Finland (FI), Belarus (BY), Kazakhstan (KZ), Sweden (SE), Ukraine (UA), Turkey (TR) and Norway (NO)). In order to perform this task, changes in the open-source EMEP/MSC-W model were necessary. These changes included a split of the Russian territory within the open-source EMEP/MSC-W calculation domain

into eight administrative subjects.

Federal district level

After the decision to use the geographical regions of the federal districts as new GAINS Russia model regions, data pre-processing was performed. This was necessary in order to perform source-receptor modelling for the regions with the extended grid version of the EMEP/MSC-W model. The following input data considerations were framing this task:

- Emissions: NO_x, SO_2, NH_3, PM_{10}, $PM_{2.5}$, NMVOC, CO;
- Emission levels: CEIP data for the year 2008;
- Regions: the six European regions of Russia to be introduced into the GAINS Russia plus one additional aggregated European region consisting of the Central Federal District region and the Larger Moscow region. This aggregated region was not introduced into the GAINS model but used to do necessary source-receptor modelling for the Central Federal District as one separate region.
- Sectors – emission sources: SNAP (level 1) sectors.

The results necessary for further modelling with the extended-grid EMEP/MSC-W model were obtained through the following stages:

1. Polygonal objects were created for the regions and for the EMEP grid cells in the ArcView GIS. By this, the geographical coordinates of the regions were linked to the coordinates of the EMEP grid cells. The result of this re-aggregation is shown in Figure 4;

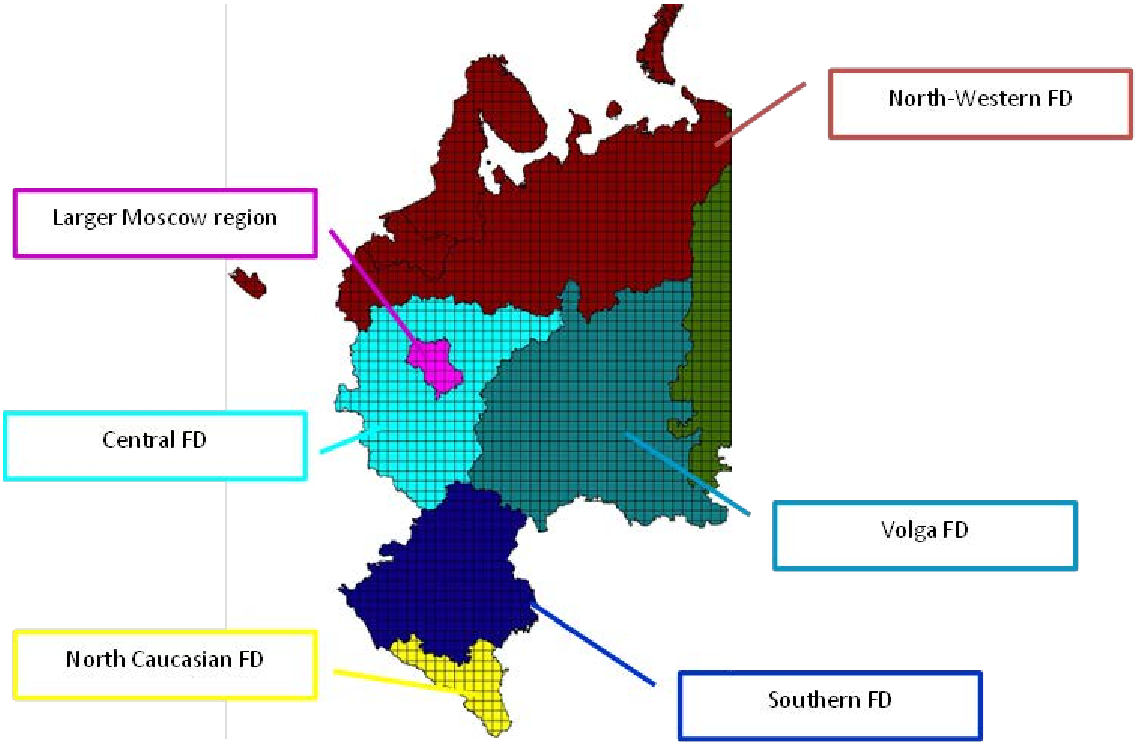

Figure 4: Splitting the European territory of the Russian Federation into EMEP grid cells.

2. Fractions of the regions in the EMEP grid cells were calculated by dividing areas of the regions covered by a certain EMEP grid cell into the cell area;

3. CEIP Emission data for each pollutant were allocated to EMEP grid cells with the help of a specially developed Fortran programme. The result of this stage for CO and SO_2 is presented in Figure 5.

4. Data on the gridded emissions and the regional fractions were transformed into a format needed for calculations with the extended grid EMEP/MSC-W model. Extracts from a fraction file and an emission file are shown in Appendix 5.

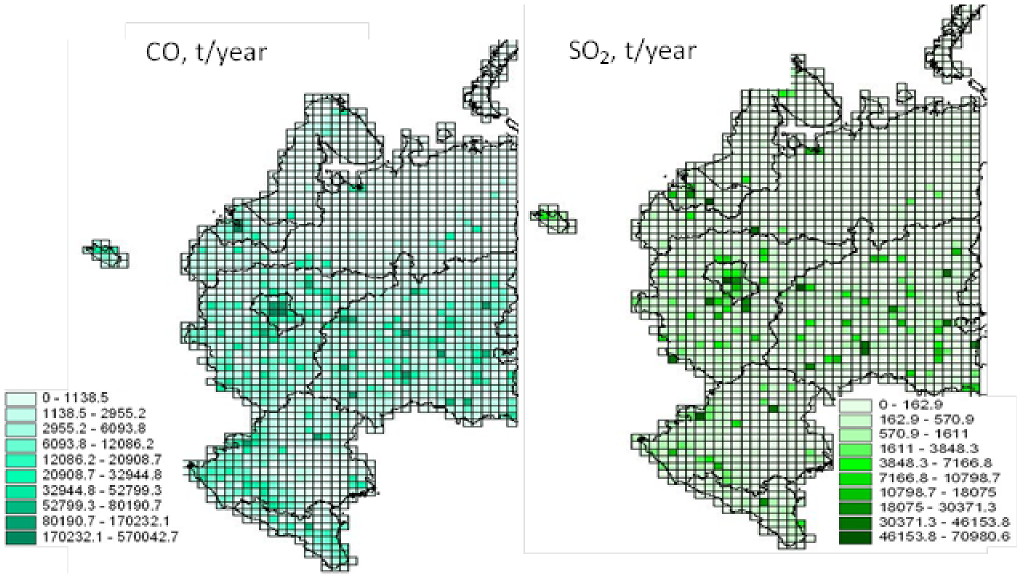

Figure 5: Spatial distribution of CEIP CO and SO_2 emission data per EMEP grid cells.

2.3.2 Extended grid EMEP/MSC-W modelling used for update of the GAINS Russia model

The EMEP/MSC-W model, version rv3.5.25, was used for source-receptor (SR) calculations in this project. The detailed description of this model version can be found in Simpson et al., 2003, whereas the recent model development is documented in Simpson et al., 2012.

The SR calculations were performed for meteorological conditions of 2008. The meteorological input data for those runs were produced by the ECMWD-IFS model (Tsyro et al., 2010). The model version and the meteorological year were specifically chosen the same as for SR calculations performed in 2010 and presented in Tsyro et al. (2010). This choice allowed the use of earlier SR results and to provide SR data for all other European countries for implementation in the GAINS Russia model.

For implementation in GAINS, SR calculations were performed for six of the Russian regions presented earlier, namely North-Western Federal District (NWD), Larger Moscow region (LMR), Central Federal District excluding Larger Moscow region (CFD), Volga Federal District (VFD), Southern Federal District (SFD), and Caucasian Federal District (NCD). Additional model calculations were made for the aggregated Central Federal District region and Moscow region (CFM).

SR calculations required one Base calculation including emissions from all regions and calculations for each of the emission regions considered, where emissions from the region are reduced (“country calculation”). Then, the difference between the Base calculation and the country calculation gave the contribution from emissions in the considered country to the total concentration/deposition field. Due to non-linearity of chemical processes at least four calculations were necessary for each emission region, in which individual emissions were reduced by 15%:

- SO_x;
- NO_x and primary $PM_{2.5}$ and coarse PM;
- NH_3;
- NMVOCs.

The methodology and linearity test of EMEP/MSC-W SR calculations are described in detail in Wind et al. (2004).

Thus, to produce data required for SR assessments for six European GAINS Russia regions and one aggregated Moscow region, a total of 29 (7x4 + 1) annual calculations were performed. As described above, the calculations were carried out on the non-extended grid (Appendix 2), which do not cover the Russian regions east from the Ural, while emissions from all European countries was included.

Data files with annual and monthly mean fields of air concentration and deposition were produced. The list of components included in the SR calculations is provided in Table 1. In addition, the earlier SR calculation results for all European countries were used as the basis for completeness and consistency of SR parameterisation within the GAINS Russia model.

Table 1: Total annual emissions in the considered regions in 2008, used in the SR calculations, kiloton (shaded figures indicate regions with largest emissions for individual pollutants)

Regions	SO_x	NO_x	NH_3	NMVOC	CO	$PM_{2.5}$	PM_{coarse}
North-Western Federal District (NWD)	244	452	49	312	1476	54	27
Central Federal District (excluding Larger Moscow region) (CFD)	398	752	146	437	2273	96	49
Larger Moscow Region (LMR)	142	469	38	283	1455	48	24
CFM (CFD + LMR)	540	1221	184	720	3728	144	73
Volga Federal District (VFD)	649	1173	239	826	3729	186	95
Southern Federal District (SFD)	200	406	78	292	1383	49	26
Caucasian Federal District (NCD)	92	236	52	159	798	30	16

The EMEP/MSC-W modelling results and necessary additional information were then used in the updating of the GAINS Russia model.

2.4 GAINS Russia model adaptations

In this project, the GAINS Russia model was adapted and updated in several aspects.

First of all, project results on the suitable geographical representation of the Russian Federation in the GAINS Russia model were implemented and translated into EMEP grid cells. This included updating of all schemas and calculations in the model, as well as scripts presenting the results in the model. The 24 regions in the old version of GAINS Russia were converted into nine regions.

Second, the results from the extended-grid EMEP/MSC-W modelling in this project was converted into linear source-receptor matrices on a region-to-grid level and introduced into the GAINS Russia model using a method consistent with earlier similar exercises (Amann et al., 2004). These describe transboundary emission fluxes between the new GAINS Russia regions and the neighbouring countries.

Following the development of linear source-receptor matrices, it was possible to proceed with introduction of the environmental and human health impact analysis feature into the GAINS Russia model. For the environmental impact calculations, the project group used the calculation methodology described in Amann (2012) and Amann et al. (2004), and information on ecosystem sensitivity for the EMEP grid cells in the European part of Russia as reported in 2008 (CCE personal communication, 2012). The methodology presented in Amann et al. (2007) was used to enable calculations of human health impacts. Human health impact from air pollution was in GAINS Russia introduced as loss in life expectancy from long term exposure to $PM_{2.5}$. The environmental and human health impact analysis in the GAINS Russia model was only introduced for the European part of Russia. Introduction of this feature for the Asian part of Russia was considered too resource-consuming and unnecessary for the objectives of this project.

In order to enable cost efficiency calculations of control strategies for the regions of the Russian Federation, the control cost calculation feature of the GAINS Russia model was activated and updated so that the functionality was identical to the GAINS Europe model.

Finally, in order to get an internationally consistent scenario as support for scenario calculations in Russia, the emission precursor data for Russia in selected GAINS Europe scenarios were disaggregated into Russian regions by using population density as a proxy for emission intensity.

2.5 Emission precursor data inventory and consistency checks for the Russian Federation

The new representation of regions in the GAINS Russia model required compilation and conversion of a new set of emission precursor data for the regions.

As presented earlier, emission precursor data sets for the Russian Federation were disaggregated based on population shares of the region as a first approximation. The main information source used by IIASA for compilation of emission precursor data for the region outside of EU is the World Energy Outlook series published by the International Energy Agency (IEA). For these data sets, the World Energy Outlook 2009 was used (IEA, 2009). Population shares are given by official statistics such as census data from Rosstat. Following this initial distribution, further adjustments were made based on other data sources.

There were two basic approaches feasible for input data collection and energy balance calculations for the GAINS model:

- A top-down approach based on total fuel consumption and energy production data at the level of administrative units or geographical regions;
- A bottom-up approach based on energy production data at the level of power plant units (large point sources of emissions).

These two approaches were applied in combination when feasible.

2.5.1 National data availability: Administrative unit level

The following sources of statistical data for the years 2005 and 2010 were used:

- Federal State Statistics Service (Rosstat);
- Main interregional center for processing and distribution of statistical information under the authority of the Federal State Statistics Service;
- Territorial bodies of State inspection for Road Traffic Service;
- Informational-analytical edition "Automobile market in Russia".

Necessary statistical data were collected for all the federal districts in the European territory of the Russian Federation. There were, however, certain difficulties in the data set compilation for the GAINS Russia regions:

- The North Caucasian Federal District was separated in 2010; in 2005 it was still a part of the Southern Federal District which means that available statistical data are aggregated;
- The Larger Moscow region is officially a part of the Central Federal District, so data for the whole Central Federal District needed to be split into the Larger Moscow region and the Central Federal District excluding Larger Moscow region.

Due to these difficulties, complete data sets for new GAINS Russia regions, based on the statistical data collected in the project, were not possible to create during the course of this project. However, for the Volga Federal District, the data set was compiled and compared to the approximated data set developed.

2.5.2 National data availability: Power plant unit level

For most of the federal districts, information was not available from other sources than statistics from Rosstat. Because of the lack of detailed information for some federal districts, it was useful to combine Rosstat data with information available through different studies and scientific publications. Scientific and technical reports available online were used to supplement the list of available statistical data sources with expert evaluations. These supplementary sources of available data can in the future be used for further validation and improvement of GAINS input data sets.

For the North-Western Federal District, energy production is especially well documented in detailed level in Efimov (2007) and CENTEK (2010), with focus on the potential for renewable energy in the Barents region. Other useful sources of information are IEA (2002), IEA (2005), Bashmakov et al. (2008), Abdurafikov (2009), and Trudeau & Murray (2011). Some studies like IEA (2002), IEA (2005) and Grammelis et al. (2006) list the largest power plants in the Russian Federation. An example of available spatial information can be seen in Figure 6. It was estimated from available data for the North-Western and Central Federal Districts that large combustion plants account for over 80% of the total energy use in energy sectors. The largest "grey area" was energy use in industrial boilers, which have not been systematically taken into account in inventories and are not typically listed in reports either.

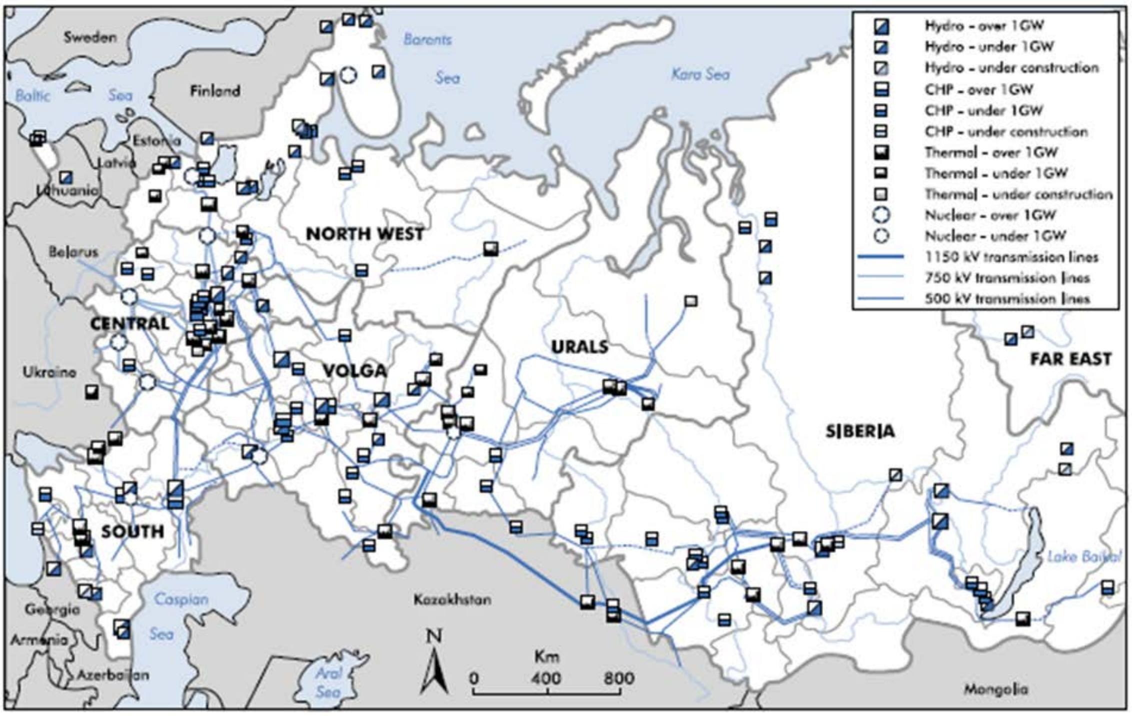

Figure 6: Map of power stations in the Russian Federation (IEA, 2005)

2.5.3 Transformation of national data into the GAINS format

General principles of energy balance

The total energy balance is a crucial check point when estimating the reliability of the national input data in the GAINS templates.

It is a common situation that only part of the needed data for the GAINS templates is available from national input data sources. If so, data not found in national input data sources should be calculated based on expert evaluations or other available statistics. During this process, it is important that the overall energy balance in the GAINS input tables (EN_TOT) is adjusted so that:

- Fuel use at power plants is equal (as far as possible) to energy production in form of electricity and heat, with respect to energy efficiency (conversion & on-site energy losses);

- Total national heat production (in energy sector and by industrial boilers) is equal (as far as possible) to total national heat consumption (mostly by industry and domestic sector), with respect to eventual national heat export or import as well as transmission and on-site losses;

- Total national electricity production by energy sector is equal (as far as possible) to total national electricity consumption (by industry, domestic sector and to some extent by transport), with respect to national electricity export or import as well as transmission and on-site losses;

Balance adjustments to follow these principles depend on the availability of different types of data.

Standardised data transformation into GAINS format

To transform the collected national input data into the GAINS format, a Russian adaptation of a Swedish standard methodology for energy data transformation to a GAINS format was used (Åström et al., 2013). This standard methodology takes into account general principles of energy balance and transforms national input data to GAINS format, and uses country-specific parameters specified in scenarios developed by IIASA. In cases where only aggregated national data are available, the methodology uses shares suggested by IIASA for splitting total national input data into sub-sectors, as well as into combustion in boilers (GAINS sector BO) and other combustion (GAINS sector OC) in the industry sector, etc. The methodology also checks total energy use as summarized per fuel to check if it corresponds to total national input data. This is necessary since fuel classification can differ between national and European statistics and models.

New GAINS input data template

In 2011, IIASA developed a new template for energy aggregation in the GAINS model. Some new features of template structure for power plants can be seen in Appendix 6. In the year 2005 only the following power plant types are "in use" (abbreviations below refer to GAINS abbreviations for sectors and fuels):
Power plants for hard coal (HC) and brown coal (BC):

- Existing power plants that have electricity generation capacity smaller than 100 MW (PP_EX_S);
- Existing power plants that have electricity generation capacity larger than 100 MW (PP_EX_L);
- New power plants for large scale coal firing (PP_NEW_L);

Power plants using other fuels:

- Existing power plants (PP_EX_OTH);
- New power plants (PP_NEW);
- Power and district heating plants with internal combustion engines (PP_ENG).

Starting from the GAINS model year 2010, it is also possible to allocate hard coal and brown coal to modern power plants with increased efficiency, supercritical or ultra-supercritical steam properties (PP_MOD), to plants with integrated gasification combined cycle (PP_IGCC) and combinations of each of these two types with carbon capture and storage (PP_MOD_CCS, PP_IGCC_CCS). Furthermore, starting from year 2015, it is possible to allocate biomass and waste fuels (OS1, OS2) to newer plant categories: PP_NEW_CCS, PP_IGCC and PP_IGCC_CCS. These features were considered during the development of scenarios for future years.

The consumption of renewable fuels is split in the new template into several separate spread-sheets corresponding to use in power plants, industry and the domestic sector, respectively.

Data transformation and energy balance within the current project were done by updating the methodology in Åström et al. (2013) with respect to the new data aggregation features.

Statistical data for the years 2005 and 2010 were collected so that each of these years could serve as a base year in the scenario development.

2.6 GAINS Europe & Russia scenario analysis

Base year comparisons

Input data sets compiled in this project were used for analysis of emissions, environmental impacts, and for analysis of existing emission control costs for the base year 2010. Emissions of pollutants (SO_2, NO_x, $PM_{2.5}$), environmental and health impacts and emission control costs for the regions in the new GAINS Russia were calculated and compared. Emissions were also compared to the national inventory results for the same year. Scenarios previously developed by IIASA with the GAINS Europe model were also used for analysis and comparisons as is illustrated in Table 2.

Table 2: Relevant comparison of new GAINS Russia scenario results between scenarios developed in this project, other scenario developed by IIASA, and national inventories

Result		**Project results**	**IIASA scenario**	**National Emission Inventory**
Emissions	SO_2 NO_x	• Volga FD • North-Western FD • Central FD	• North-Western FD • Volga FD • Sothern FD • North Caucasian FD • Central FD (including Larger Moscow region) • Central FD (excluding Larger Moscow region) • Larger Moscow region	• North-Western FD • Volga FD • Sothern FD • North Caucasian FD • Central FD (including Larger Moscow region)
	$PM_{2.5}$	• Volga FD • North-Western FD • Central FD	• North-Western FD • Volga FD • Sothern FD • North Caucasian FD • Central FD (excluding Larger Moscow region) • Larger Moscow region	—
Impacts	Eutrophication Acidification Health	• Volga FD • North-Western FD • Central FD	• North-Western FD • Volga FD • Sothern FD • North Caucasian FD • Central FD (excluding Larger Moscow region) • Larger Moscow region	—
Costs	SO_2 NO_x $PM_{2.5}$	• Volga FD • North-Western FD • Central FD	• North-Western FD • Volga FD • Sothern FD • North Caucasian FD • Central FD (excluding Larger Moscow region) • Larger Moscow region	—

The IIASA scenario used for comparison with national emission inventory data and data collected in this project was the GAINS model scenario PRIMES_BL2010_REF_Dec11, disaggregated for Russia based on population size in the different regions.

Ambition scenarios

Following the negotiations under the UNECE CLRTAP convention, the project group also analysed potential abatement costs, emissions, and emission dispersion of tentative Russian ambition levels for the North-West Federal district (NWFD) and the Central Federal District (CFD). During the agreement of a revised Gothenburg protocol, Russia indicated that an ambition level of 2005 emissions -5% would be analysed domestically (Engleryd, 2012). These -5% were analysed for different sectors by using GAINS Russia model to calculate emission dispersion, emissions and abatement costs.

3 Results

In this chapter the detailed results of the project are presented task by task, followed by the summary of the overall project results.

3.1 Regionalization and emission inventory

During this project, the territory of the Russian Federation in the GAINS Russia model was divided into regions corresponding to federal districts (with exception of the Larger Moscow region and Central Federal District), see map in Figure 7.

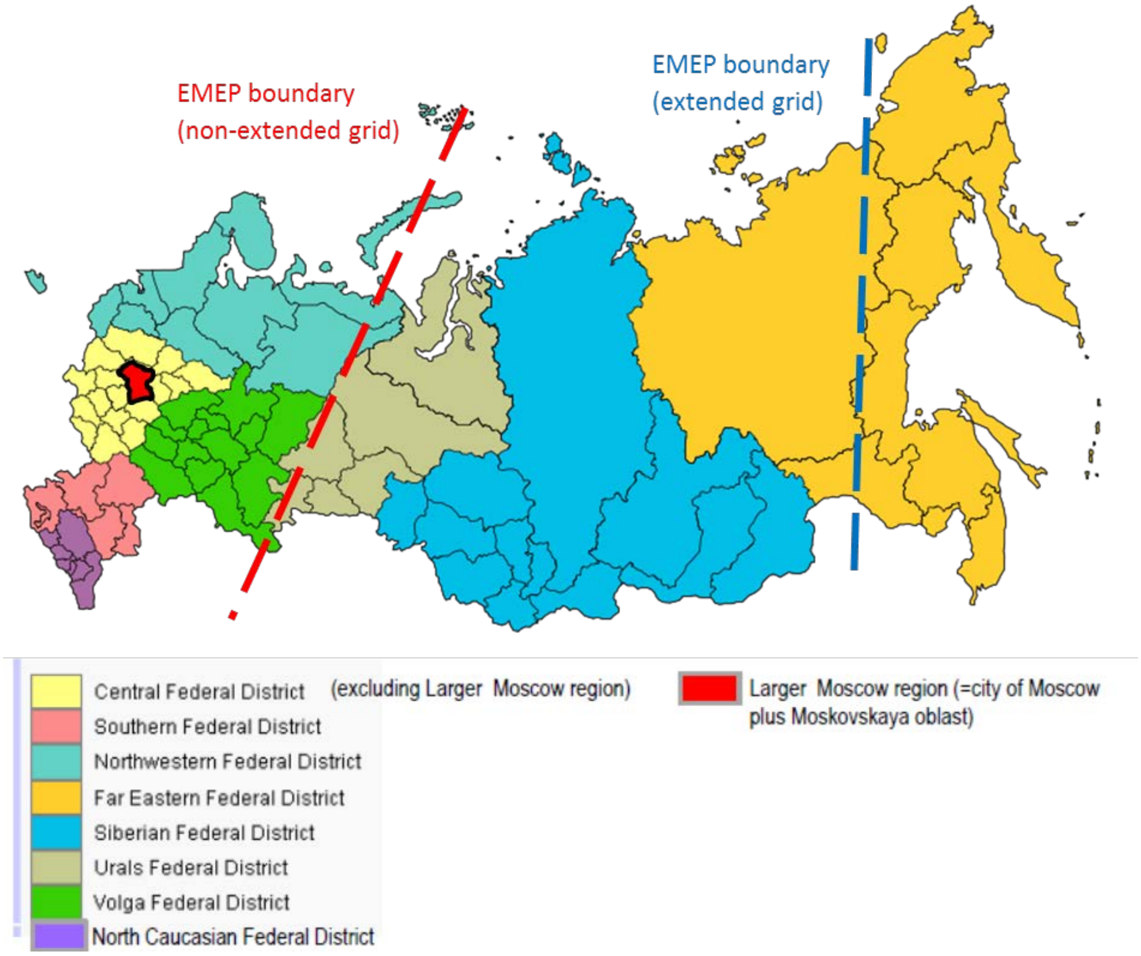

Figure 7: Russian regions in the new GAINS Russia as a result of the model disaggregation in 2012

This map served as a basis for the EMEP/MSC-W source-receptor modelling work, GAINS model adjustments and activity data collection.

3.2 EMEP/MSC-W modelling results

For the EMEP/MSC-W source-receptor modelling, sector-specific emissions and emissions by EMEP grid cells were necessary as input data. Furthermore, EMEP grid cells needed to be allocated to the Russian regions considered in this project. The EMEP/MSC-W model calculations produced source-receptor data that were used for constructing source-receptor matrices in the GAINS model, blame matrices, concentration and deposition maps etc.

3.2.1 Main results from modelling with the non-extended grid for soft-linking with the GAINS Europe model

In this project the non-extended version of the EMEP/MSC-W model was used to calculate emission fluxes between the Russian regions as described in the GAINS Europe model, and the consequential impact on deposition and concentrations. These calculations were performed for different emission levels corresponding to implementation of specific emission control options.

Maps of nitrogen and sulphur deposition caused by emissions originating in the GAINS Europe SPET and KOLK regions are presented in Appendix 7. The maps illustrate deposition levels in the following two cases: when there is no emission control and when an emission control strategy is applied. Based on the maps, emission fluxes between the SPET and KOLK regions and European countries (excluding Russia) are calculated for the case with a hypothetical additional use of emission control technologies, see Figure 8.

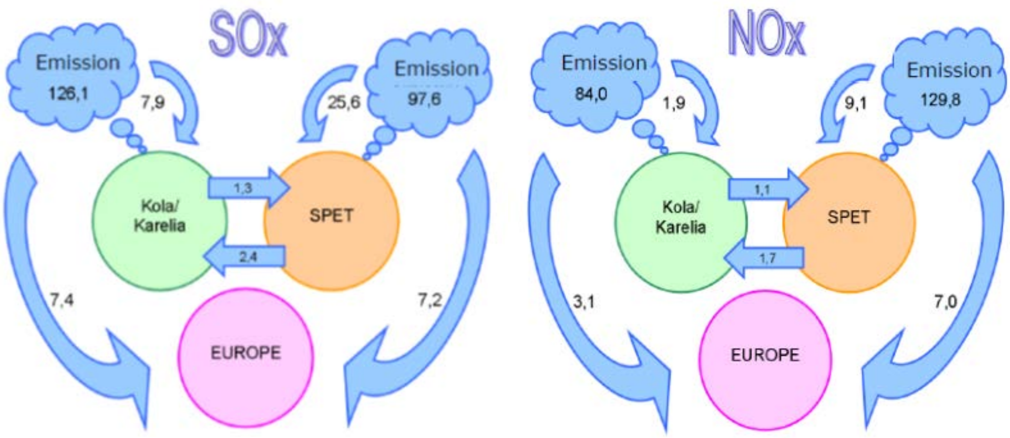

Figure 8: SO_2 and NO_x transboundary fluxes, kt in terms of S and N; SPET and KOLK regions, 2005, emission control strategy applied

The impact of emission control technologies is in the GAINS model represented as emission control strategies. For this project, emissions from the SPET and KOLK regions in a 'no-control' analysis were compared with the implementation of the following emission control options in 2005:

- For heavy duty trucks on gasoline – 100% implementation of Euro I;
- For heavy duty trucks on diesel and for passenger cars on gasoline – 8% implementation of Euro II and 16% implementation of Euro III;
- In the industry, conversion and power sectors – 8% implementation of combustion modification (NO_x control);
- For industrial sources on coal – 8% implementation of wet gas desulphurization;
- For industrial sources on medium distillates – 20% implementation of wet gas desulphurization;
- For power plants – 50% implementation of wet gas desulphurization;
- Low sulphur diesel: 0.045% S in the transport sector, 0.2% S in other sectors.

In addition to the scenario analysis presented above, the non-extended version of the EMEP/MSC-W model was used to calculate Russian versions of the blame matrices, in which blame matrices between eight subjects of the Russian Federation and ten nearby countries were developed. One of the blame matrices is shown in Appendix 4.

3.2.2 Main results from extended grid EMEP/MSC-W modelling used for update of the GAINS Russia model

This chapter presents the main results of the SR calculations performed with the EMEP/MSC-W model.

From the calculated Base calculation pollutant fields and the fields due to 15% emission reductions, annual concentration and deposition fields due to emissions from each of the seven Russian districts were constructed. Some examples are given in Figure 9, which shows concentrations of NO_2 and $PM_{2.5}$ due to emissions in the Central Federal District excluding Larger Moscow region (upper panels) and in the Large Moscow Region (lower panels) in 2008. The clear footprint of traffic emissions in Moscow was pronounced in both the NO_2 and $PM_{2.5}$ maps, while those from Central Federal District showed much lower levels. The concentration of NO_2, which is considered to be a health hazardous pollutant, exceeded 6 μg N/m^3 in the most polluted grid cells within the city. It is interesting to note that these NO_2 levels, calculated using the emission distributions by the new GAINS Russia regions, appeared much lower than those based on original CEIP data with emissions split by old GAINS Russia regions (in the latter case NO_2 exceeded 13 μg N/m^3).

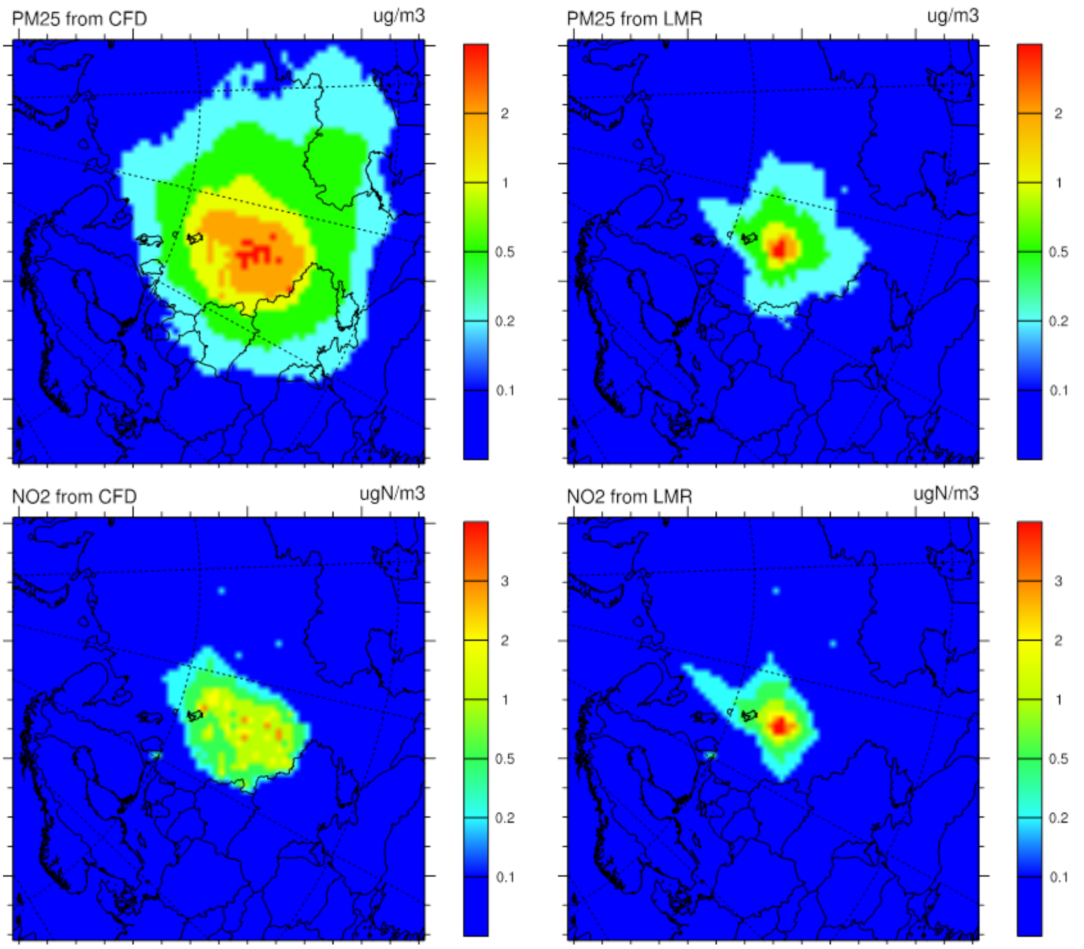

Figure 9: Concentrations of $PM_{2.5}$ (upper panels) and NO_2 (lower panels) due to emissions in the Central Federal District excluding Moscow (left) and in the Large Moscow Region (right) in 2008. Units: µg $PM_{2.5}/m^3$ and µg N/m^3, respectively

The maps in Figure 10 show the concentrations on $PM_{2.5}$ from the same regions, disaggregated to primary and secondary components, namely primary $PM_{2.5}$ ($PPM_{2.5}$) and Secondary Inorganic Aerosols (SIA = sulphate + nitrate + ammonium aerosols). The differences in the composition of $PPM_{2.5}$ from the mega-city of Moscow (LMR) and the more rural Central Federal District (CFD) are clearly seen. Large traffic emissions in Larger Moscow region were manifested by a hotspot of high $PPM_{2.5}$, while $PPM_{2.5}$ from Central Federal District showed much lower levels. On the other hand, SIA concentrations from Central Federal District were considerably higher than those from Larger Moscow region due to larger ammonia emissions from agricultural sector (ammonia neutralizes sulphur and nitrogen emissions from industrial and traffic sources forming ammonium sulphate and ammonium nitrate). Since primary PM is emitted directly as particles and originates mostly from low elevation emissions, they are subject to a faster removal from air. Thus their influence has a more local character compared to SIA, which have longer lifetimes.

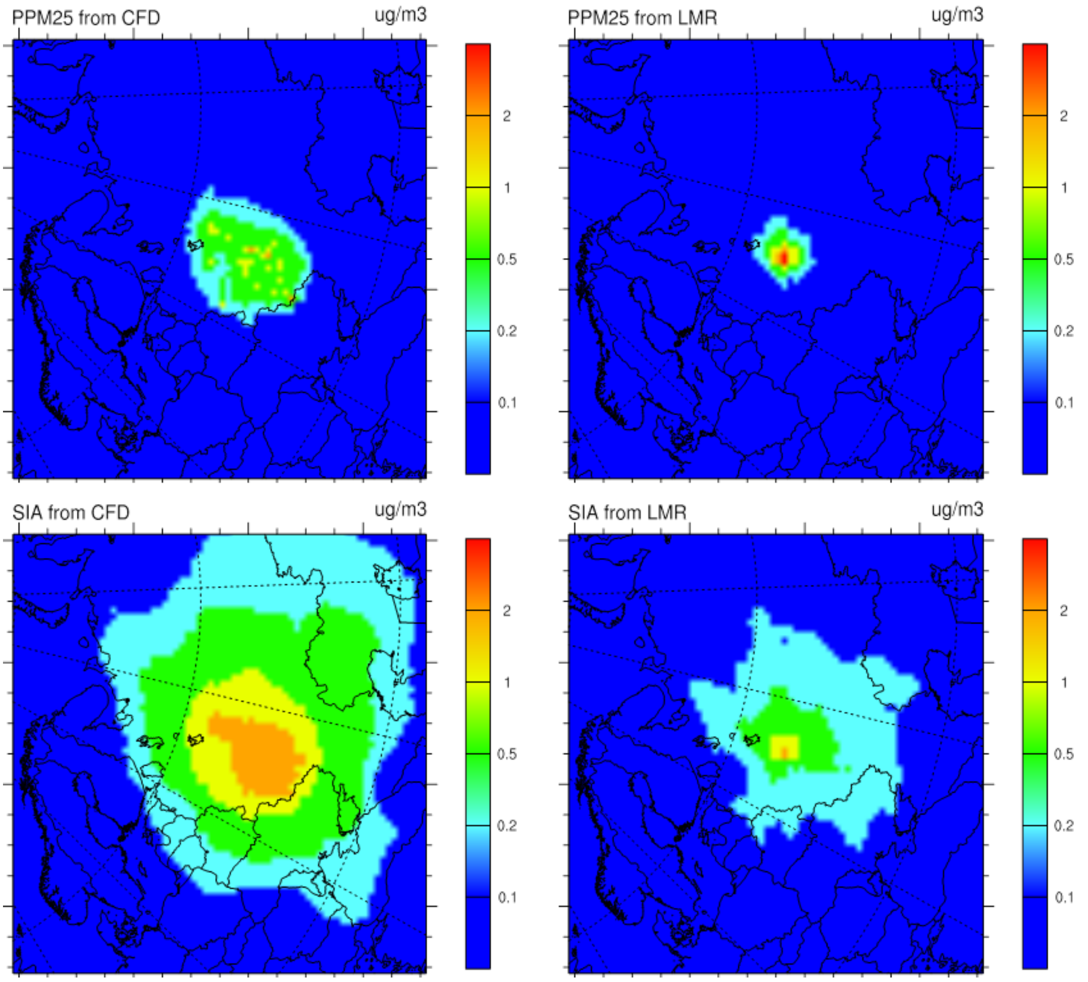

Figure 10: Concentrations of $PPM_{2.5}$ (upper panel) and SIA (lower panel) due to emissions in the Central Federal District excluding Moscow (left) and in the Large Moscow Region (right) in 2008. Unit: $\mu g/m^3$

The maps in Figure 11 compare total deposition of oxidized sulphur and nitrogen and reduced nitrogen from Volga Federal District (VFD) and North-Western Federal District (NWD) (notice the different colour scales for different components). The deposited amounts of all those components due to emissions in the Volga Federal District were greater than corresponding deposition due to emissions in the North-Western Federal District, particularly for reduced nitrogen. This was due to the large emissions of ammonia from agricultural activities in Volga Federal District. It is seen that the distance of influence is relatively short for reduced nitrogen (which is efficiently removed by dry and wet deposition). The influence distance is larger for oxidised sulphur, and even more so for oxidized nitrate.

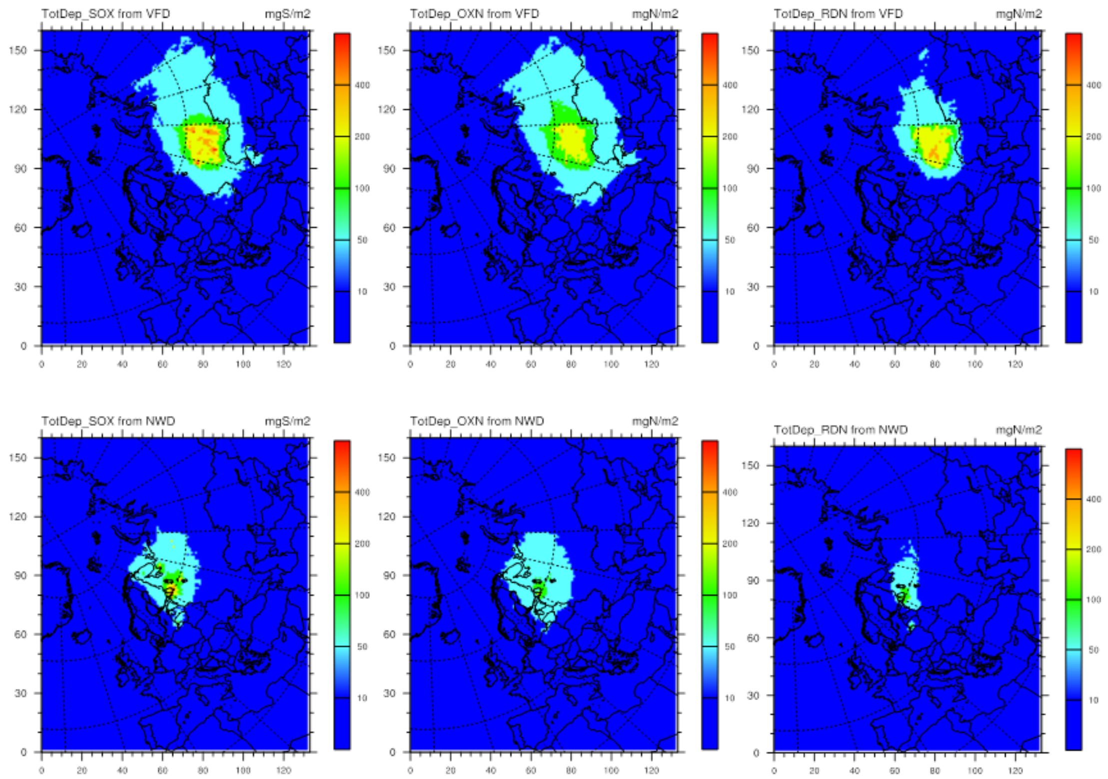

Figure 11: Total deposition of oxidized sulphur (left), oxidized nitrogen (middle) and reduced nitrogen (right) due to emissions in the Volga Federal District (upper panels) and the North-Western Federal District (lower panels) in 2008

Based on the calculated fields, trans-regional pollution with respect to air concentration and deposition was calculated. Appendix 3 provides tables with so-called blame matrices for oxidized sulphur, oxidized nitrogen and reduced nitrogen (SO_x, NO_x and NH_3) for the considered regions in 2008. Among the Russian districts, the Volga Federal District (VFD) was the largest source region of deposition of all SO_x, NO_x and NH_3, closely followed by the Central Federal District (CFD). On the other hand, Volga Federal District received the greatest amount of acidifying and eutrophying deposition. The second largest receiver of SO_x and NO_x deposition was the North-Western Federal District (NWD), whereas Central Federal District received the second largest amount of NH_3 deposition.

The largest portion of all deposition in any of the Russian regions originated from emissions in the region itself (indigenous deposition). However, there are two interesting exceptions in the case of pollution exchange between the Larger Moscow region and the surrounding Central Federal District excluding Larger Moscow region. The Central Federal District appeared to be the largest source of SO_x deposition in the Larger Moscow region, which was due to several large point sources (power plants) outside the megacity region. On the other hand, due to its large traffic emissions, the Larger Moscow region was the major contributor to NO_x deposition in the neighbouring Central Federal District. The relative contribution of trans-regional deposition was largest in the North-Western Federal District, constituting 47%, 64% and 54% for SO_x, NO_x and NH_3, respectively, while the relatively smallest deposition due to trans-regional fluxes occurred in North-Caucasian Federal District (23%, 29% and 14%, respectively).

It should be pointed out that there are three main factors affecting contribution of surrounding regions (countries or districts) to pollution in a certain region:

- Meteorological conditions (prevailing direction of air transport);
- The amount of emissions in the surrounding regions;
- The proximity of different emitting regions.

Moreover, the trans-regional pollution depends on the pollutant, especially its emission height and removal efficiency in air. Also, secondary components typically contribute to long-range pollution more than primary components (for more discussion, see van Loon et al., 2005).

3.3 Results of the GAINS Russia model adaptations

The GAINS Russia model update and adaptation resulted in a number of new features in the GAINS Russia model.

First of all, the regions identified as suitable, due to their representation of federal districts, were introduced into the GAINS Russia model. These were six separate European regions, and three separate Asian regions, see Table 3.

Table 3: New regionalisation in the GAINS Russia model

Continent	Region
Asia	Far East
Asia	Sibiria
Asia	Ural Asia-Chelabinskaya, Sverdlovskaya, Kurganskaya
Europe	Moscow
Europe	Northern Caucasus
Europe	Northwestern
Europe	Other Central
Europe	South
Europe	Volga

Secondly, the source-receptor calculations performed for the same regions with the extended EMEP/MSC-W model were linearized and introduced as 'region-to-grid'-specific emission transfer matrices into the GAINS Russia model.

Following this it was then possible to allow for environmental and human health impact features, as well as emission scenarios with emission control costs explicitly calculated. Emission scenarios can only be created for Russian regions in Europe, while other European countries contribute to the environmental and human health impacts in Europe according to already established emission transfer matrices in the GAINS Europe model. Deposition and concentrations of air pollutants from Asian part of Russia and from other countries in Asia (EECCA countries) are indicated as background values. In the new GAINS Russia model, the following environmental and human health indicators are possible to calculate in scenarios:

Air quality indicators:

- Concentrations of fine particulate matter
- Deposition of sulphur and nitrogen compounds

Health and environmental impacts indicators

- Health impacts attributable to $PM_{2.5}$ exposure
- Excess of critical loads for acidification in forest ecosystem areas and for eutrophication in all ecosystem areas

Finally, two scenarios already developed for the GAINS Europe model were disaggregated into the GAINS Russia model. The disaggregation was based on population shares in the different regions (scenario names: PRIMES_BL2010_REF_Dec11 & PRIMES_BL2010_REF_current).

Given the available input data, the new GAINS Russia model features presented above differed between the European and Asian part of Russia. For the six European parts of Russia the new GAINS Russia model can calculate scenario-specific emission control costs as well as environmental and human health impacts. For the three Russian regions, the GAINS Russia model calculates emission scenarios.

3.4 Emission precursor data inventory and consistency checks for the Russian Federation

The data inventory based on Russian statistics was performed for the Volga region in the GAINS model. The result from the data inventory was introduced into the GAINS Russia model scenario 'Atmosphere'. For the other regions, the disaggregated IIASA-scenarios were used.

Activity data

Input of different regions and fuel types into the total energy consumption in the European part of Russia in 2010 is shown in Table 4.

Table 4: Fuel- and region-specific energy use in the European part of Russia, 2010

Fuel use, Peta Joule (PJ)	Larger Moscow region	Central FD	North-Western FD	Southern FD	Volga FD	
					IIASA	SRI
BC1: Brown coal/lignite, grade 1	8	37	16	16	35	6
BC2: Brown coal/lignite, grade 2	0	0	0	0	0	11
HC1: Hard coal, grade 1	66	293	127	129	279	49
HC3: Hard coal, grade 3	0	0	0	0	0	34
DC: Derived coal (coke, briquettes)	13	56	24	25	54	55
OS1: Biomass fuels	6	29	12	13	27	14
OS2: Waste fuels	6	28	12	12	27	0
HF: Heavy fuel oil	83	369	160	163	352	569
MD: Medium distillates	66	294	127	130	280	232
GSL: Gasoline	77	342	148	151	327	373
LPG: Liquefied petroleum gas	16	71	31	31	67	32
GAS: Natural gas	715	3162	1370	1398	3016	3787
REN: Renewable energy	2	8	4	4	8	0
HYD: Hydroenergy	12	53	23	24	51	88
NUC: Nuclear energy	121	536	232	237	512	117
ELE: Electricity	-5	-22	-10	-10	-21	-28
Total	1189	5256	2278	2323	5013	5341

Appendix 8 contains diagrams summarizing activity data compiled for the base year 2010 for the Volga Federal District. Total energy use distributed by fuels and by sectors is shown in comparison, as well as electricity and heat production and consumption rates.

Certain data discrepancies between the IIASA scenario for Volga and the Russian data inventory for the Volga Federal District were noted. The district inventory showed 7% higher total energy use than in the IIASA scenario, mainly due to a more extensive use of heavy fuel oil, hydro-energy and natural gas. At the same time, use of biomass, nuclear energy, and medium distillates were lower.

In both data sets, natural gas was the dominating fuel (60% of the total energy use in IIASA data, 71% according to district statistics). In the IIASA data, the second most used energy carrier was nuclear energy (10% of total energy use), followed by heavy fuel oil and gasoline (7% each). According to district statistics the second most used energy carrier was heavy fuel oil (11%).

The data in the IIASA scenario assumed a different distribution of coal by types and grades than national statistics. The use of biomass assortments such as black liquor and waste fuels were, in the IIASA scenario, almost as high as the use of biomass assortments such as fuel wood and agricultural residues. In the district statistics, there was no use of fuel wood and agricultural residues. The use of other types of renewable energy (geothermal, wind and solar energy) was also zero in the district statistics.

The distribution of energy use by sectors was quite similar in both data sets. The three dominating sectors (62-67% of total energy use) were power plants, industrial combustion and the domestic sector. The only significant difference between the data sets was the energy distribution between road and non-road mobile sources. The IIASA scenario indicated a more extensive fuel use by non-road mobile sources than by road traffic, whereas the district statistics indicated the opposite.

Electricity and heat production were 9- 11% higher in the district statistics; however, both in the IIASA scenario and in district statistics it was indicated that 3-4% of the produced electricity was exported.

Use of technologies to control emissions (control strategy)

There was no district-specific inventory performed on the use of emission control technologies in this project. Therefore, the best available estimate from the IIASA scenario on use of control technologies was assumed to apply equally to all the regions in the European part of Russia. In this best estimate, the following emission control options were used in the Russian regions in 2010 and 2020:

Transport sector emission control:

- For all mobile sources on gasoline – 50% implementation of low sulphur gasoline (0.001 %S);
- For heavy duty vehicles on gas – 100% implementation of Euro I;
- For passenger cars and light commercial trucks on gas – 100% implementation of Euro II;
- For heavy duty vehicles on diesel, passenger cars and light commercial trucks on gasoline, diesel and liquefied petroleum gas – 40% implementation of Euro I, 10% implementation of Euro II, 22% implementation of Euro III;
- For motorcycles on gas and cars with 2-stroke engines – 32% implementation of Euro I, 5% implementation of Euro II;
- For non-road sources with 4-stroke engines on diesel – 34% of Euro I;
- For construction, agricultural railway and inland waterway mobile sources on diesel – 34% implementation of stage 1 NOx and VOC control; 100% implementation of low sulphur diesel oil - stage 1 (0.2 % S);

- For heavy duty vehicles, passenger cars and light commercial trucks on diesel – 100% implementation of low sulphur diesel oil - stage 2 (0.045 % S);
- For national maritime shipping on diesel and heavy fuel oil – 5% implementation of combustion modification(NOx control);

Industry, conversion and power sectors emission control:

- For all power plants – 50% implementation of in-furnace SO_2 control by lime injection;
- For existing power plants on coal and biomass – 30% implementation of combustion modification (NOx control); 50-100% implementation of ESP and 10-30% implementation of cyclones (100% in sum for each activity-fuel combination);
- For new power plants – 100% implementation of ESP;
- For industrial boilers on coal and biomass – 50-100% implementation of ESP and 10-30% implementation of cyclones (100% in sum for each activity-fuel combination);
- For industrial oil boilers – 30% implementation of good housekeeping at existing power plants and 50% implementation of good housekeeping at new power plants;
- For mining industry – 30% implementation of good practice;
- For aluminium production, basic oxygen furnaces, coke ovens, glass production, refineries, and sinter plants – 40% implementation of cyclones and 59% implementation of ESP;
- For cast iron, cement production, and lime production – 100% implementation of ESP;
- For carbon black production, electric arc furnaces, and non-ferrous metal production – 40% implementation of cyclones and 59-60% implementation of high efficiency deduster;
- For fertilizer production – 5% implementation of cyclones and 95% implementation of high efficiency deduster;
- For open hearth furnaces – 50% implementation of cyclones;
- For pig iron production in blast furnaces – 40% implementation of cyclones, 30% implementation of ESP and 30% implementation of high efficiency deduster;
- For small industrial and business facilities – 60% implementation of good practice;

Domestic sector emission control:

- For residential-commercial automatic boilers – 25% implementation of cyclones for boilers on coal and 5% – for boilers on biomass;

- For residential-commercial manual boilers on coal – 10% implementation of cyclones;
- For biomass single house boilers – 9% implementation of improved boilers;
- For residential-commercial cooking stoves on coal—3% implementation of stove improvements for stoves on coal and 9% – for stoves on biomass;
- For domestic oil boilers – 15% implementation of good housekeeping;

3.5 GAINS Europe & Russia scenario analysis

Base year comparisons

With the new GAINS Russia model developed in this project it was possible to simulate the effect of emissions originating in one region on environmental indicators in other regions. The results of the simulations for the year 2010 are presented below. For the Volga Federal District, model runs were made for two data sets: the IIASA scenario and the data set based on district statistics, and the results were compared.

Emissions

Emissions of NOx, SO_2 and $PM_{2.5}$ calculated for six European regions of the Russian Federation are summarized in Appendix 9. NO_x and SO_2 emissions are compared to the Russian national emission inventory results.

For both NOx and SO_2, the emissions reported in the Russian national emission inventory are lower for all regions than emission levels calculated in GAINS. The distribution of emissions between the regions was quite similar. The Central Federal District was the largest source of emissions for all three considered pollutants, representing about 32-48% of the total emissions in the European part of Russia. The Larger Moscow region accounted for 17-18% of the Central Federal District emissions. The Volga Federal District was responsible for about one third of emissions in the European part of Russia for all considered pollutants. The North Caucasian Federal District was the least polluting region in 2010. The total emission levels for the European part of the Russian federation are presented in the table below:

Table 5: Comparison of SO_2, NO_x, and $PM_{2.5}$ emission estimates in 2010 for the European part of Russia

Emission source	2010 SO_2 emissions (kton)	2010 NO_x emissions (kton)	2010 $PM_{2.5}$ emissions (kton)
Russian emission inventory	1257	2075	-
GAINS Russia scenario: PRIMES_BL2010_REF_Dec11	1785	2685	767

Emissions of NOx and SO_2 calculated for the Volga Federal District, based on district statistics, were closer to the modelled emissions based on the IIASA scenario than to the inventory results. Discrepancies between the inventory results and the modelled emissions will be further investigated after the compilation of the national activity data sets for all new regions is completed. One of the reasons for the discrepancies is probably a lack of national control strategies adjusted to the regional conditions.

Ambition scenarios

For selected sectors, an emission abatement scenario of 5% was analysed with regards to NO_x and SO_2 emissions and abatement costs with the GAINS Russia model, results for the NWFD and CFD are shown in Table 6 and Table 7. Emission data for the year 2010 from IIASA was used as an approximation of emission levels in 2005, and based on these analysis was performed on cost effectiveness of abatement measures in selected sectors for some of the Russian regions in Europe 2020.

Table 6: Selected emission abatement options that would have achieved a sector-specific 5% reduction of emissions compared to 2010 levels of NO_x and SO_2 in the North-western Federal District and associated abatement costs, 2020

	NO_x		SO_2					
Emission reduction technology →	**Improvement of combustion technologies and selective catalytic reduction**		**Desulphurisation of flue gases**		**Use of low sulphur fuel**		**Lime Injection**	
Sector ↓	Reduction, kiloton (kton)	Cost. mill. €/year	Reduction, kton	Cost. mill. €/year	Reduction, kton	Cost. mill. €/year	Reduction, kton	Cost. mill. €/year
Power industry (new and existing power plants)	7.15 (5%)	2.9					18.6 (5%)	2.4
Fuel combustion in industry	2.85 (5%)	3.0	11.05 (5%)	0.9	11.05 (5%)	0.7		

The results indicated that in 2020 it would be more cost effective for the North-Western Federal District of the Russian Federation to invest in NO_x –emission reducing technologies in the power plants than in industry (~400 €/ton NO_x vs. ~1050 €/ton NO_x). Furthermore, the use of low sulphur fuel in industries would be sufficient and cost efficient in order to reach an SO_2 emission reduction of 5% for that sector (~65€/ton SO_2 vs. ~80€/ton SO_2). For these sector-specific emission reduction scenarios, the total regional emission reductions are too small for a meaningful analysis of environmental impacts in the Nordic countries.

For the CFD region the results are somewhat different than for the NWFD region.

Table 7: Selected emission abatement options that would have achieved a sector-specific 5% reduction of emissions compared to 2010 levels of NO_x and SO_2 in the Central Federal District and associated abatement costs, 2020

	NO_x		SO_2			
Emission reduction technology →	**Improvement of combustion technologies and selective catalytic reduction**		**Desulphurisation of flue gases**		**Lime injection**	
Sector ↓	Reduction, kiloton (kton)	Cost. mill. €/year	Reduction, kton	Cost. mill. €/year	Reduction, kton	Cost. mill. €/year
Power industry (new and existing power plants)	10.15 (5%)	7	-	-	4.2 (5%)	3
Fuel combustion in industry	7.8 (5%)	6.6	3.85 (5%)	0.9	3.85 (5%)	1.3

As is seen, the overall costs of a hypothetical increase in efforts to reduce emission abatement are somewhat higher in CFD than in the NWFD region. This is due to differences in the industrial and energy system structure and already implemented emission abatement options.

These emission reductions are in turn associated with changed deposition patterns for the European regions in Russia. These were analysed for NO_x emissions from the CFD in 2005 and a hypothetical 2020 for the abatement measures studied.

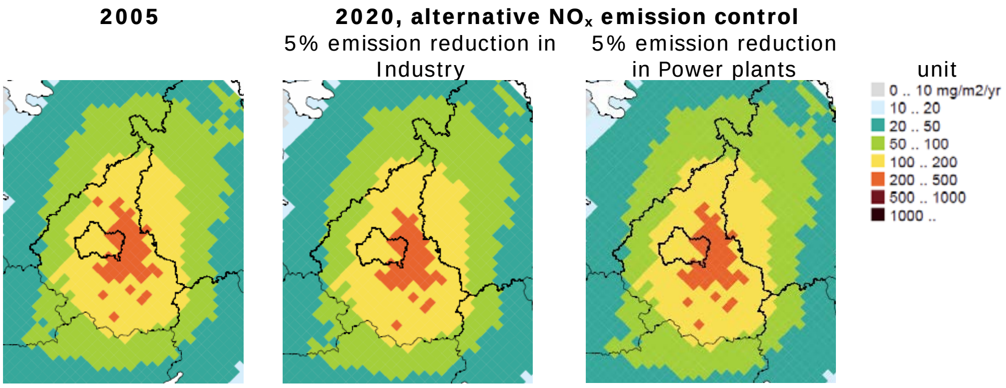

Figure 12: Region-specific deposition of oxidised nitrogen caused by NO_x emissions from CFD in 2005 and for two different hypothetical situations for 2020

Although the changes in total regional emissions are relatively small when implementing the specific emission controls, changes in deposition of oxidised nitrogen can still be seen in the model results. This is most obvious for the 5% decrease in emissions from industrial combustion sources.

The deposition pattern of sulphur caused by SO2 emissions in the CFD is in the studied baseline scenario relatively constant from 2005 to 2020.

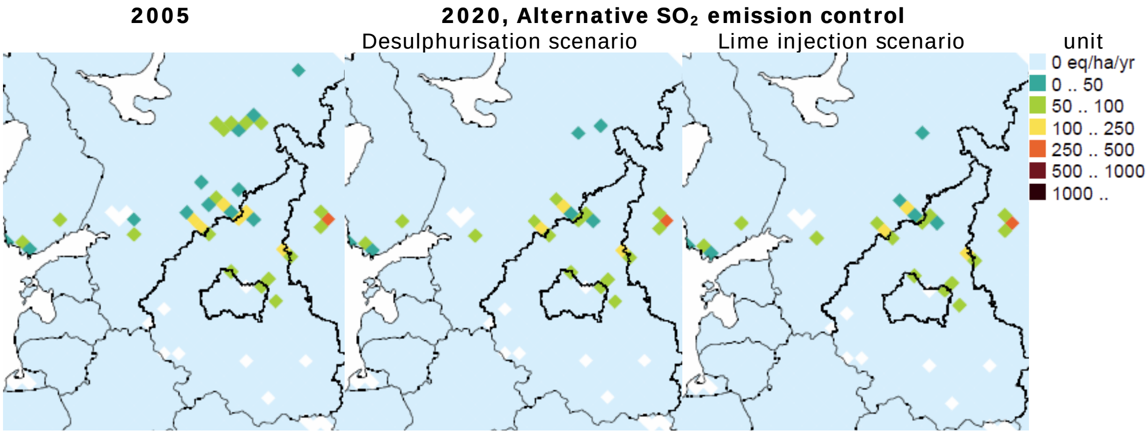

Figure 13: Region-specific acidification impacts caused by SO_2, NO_x, and NH_3 emissions from CFD in 2005 and following the hypothetical SO_2 abatement options for 2020

As can be seen, hypothetical SO_2 emission reductions in CFD 2020 would mainly have benefited the North-Western Federal District of the Russian Federation according to the model results. The option to reduce SO_2 emissions by the use of lime injection technologies in both the power plants and industrial combustion can as expected be seen to have a larger impact on acidification.

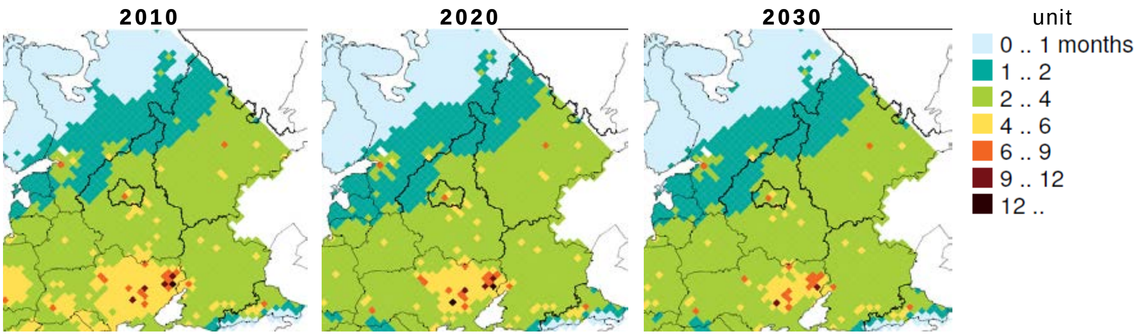

Figure 14: Modelled Geographical distribution in average loss in life expectancy for population over 30 years of age (Scenario: PRIMES_BL2010_REF_Dec11)

Although the health impacts shown in Figure 14 is smaller than previous All-European estimates they show the hot spots of St. Petersburg and Moscow and also show a small improvement in human health for the European parts of the Russian Federation. The same message, but more clearly distinguishing the Moscow region is shown in Table 8.

Table 8: Average loss in life expectancy for population over 30 years of age (months/cap) calculated with the GAINS Russia model (Scenario: PRIMES_BL2010_REF_Dec11)

Region	2010	2020	2030
Moscow	4	4	5
Northern Caucasus	3	3	3
North-western	2	3	3
Other central	2	2	2
South	3	3	3
Volga	3	3	3
Total	3	3	3

The results show that the population in the Moscow region will be subject to larger adverse health impacts compared to the other European regions of Russia throughout the scenario period.

4 Discussion

Regionalisation

The European part of the Russian Federation covers almost 40% of the entire European continent. To disregard regional differences when performing integrated assessment modelling will therefore increase the risk of producing over-simplified results. Also, the Russian Federation is comprised of a number of relatively autonomous administrative regions, with relatively independent environmental legislation. This Russian characteristic makes it even more important to represent the European parts of Russia as separate regions to the extent possible. It is however understandable that a full regionalisation of the European part of Russia hasn't been performed earlier, since an updated GAINS model seems to have been of low priority for Russian stakeholders. There are however two main obstacles that need to be overcome during the course of regionalisation. The first obstacle relates to which administrative region that should be chosen. Russia has several layers of administrative regions, Oblasts, Krays, Republics, and Okrugs, all of which are relevant administrative units. The second major obstacle relates to the fact that these are changing over time, as has been presented earlier in this report. Given that a re-regionalisation is a costly effort, this is a significant obstacle. For Russian national administrative purposes, a disaggregation of the European parts of Russia into the smaller administrative regions, oblasts, could have been preferable, but that was not feasible during the course of this project. Choosing oblasts would also have implied heavy efforts on data inventory, since there are more than 30 oblasts in the European part of Russia.

The rewards from an improved regionalisation are that the region-specific circumstances can be better represented. This is important from an emissions perspective, since emissions differ substantially between Russian regions. This is also important from an impact perspective, where the mega-city of Moscow suffers much more from air pollution related health damages than other regions of Russia. If the GAINS model wouldn't have been regionalised, these differences would not have been clearly visible and cost-effective emission abatement strategies would have been more difficult to analyse.

The choice to use Okrugs as the basis for the representation of regions in GAINS Russia enables a relatively easy activity data inventory in the future and also makes it possible to compare modelled emissions with emission inventory results for the regions.

Data & Emission inventory

As a first case study within this project the Volga Federal District was chosen for inventory of emission precursor activity data and corresponding emissions. This enabled the project group to illustrate potential differences between international statistics as reported by the IEA, but also to highlight differences in emissions caused by the population-based weighting method used by IIASA when disaggregating Russian data. Still, inventories on emission precursor data are difficult to obtain, and it is also difficult to estimate the degree of completeness in the inventories. One of the difficulties relates to the fairly de-centralised principle of data collection in the Russian Federation, where different administrative units (statistics bureau, ministry of environment etc.) collect different data. However, the data might also be available for different levels of administration (okrugs, oblasts etc.). In principle, a completeness check can't be performed until a complete inventory of emission precursor data for all regions has been performed. For continued research activities, high quality emission precursor data inventories will be of key concern. Having completed this challenge, the next most important challenge is the construction of scenarios, based on the activity data inventories for the selected base year. As of now, GAINS model input data inventories for the Russian Federation are subject to large uncertainties that will need to be dealt with.

EMEP/MSC-W model source-receptor calculations

The most important part of the EMEP/MSC-W modelling in this project was source-receptor calculations for six Russian regions performed in order to provide the GAINS Russia model with input data needed for the regionalisation and calculation of environmental and health impacts. However, the EMEP/MSC-W modelling and training performed within this project have facilitated building the capacity needed for future independent analysis by experts in the Russian Federation. It also has provided the Russian Federation with the opportunity to use both the GAINS and the EMEP/MSC-W model to perform case study analysis on, for example, impacts of emission reductions in specific oblasts.

GAINS Russia model adaptations

The GAINS Russia model has now in this project been updated and assigned a number of features already available in the larger GAINS Europe model. If future research activities are continuously performed and regionalised national input data and scenarios are introduced to the model, it can now serve the European part of the Russian Federation with the same type of policy analysis as the European version of the model. The Russian Federation can use these results as negotiation support in the CLRTAP, but also for internal needs to analyse the intra-Russian environmental and health impacts between regions, as well as the costs to reduce these impacts.

GAINS Scenario analysis

In this project only scenario analysis on stated Russian tentative ambition levels in the Revised Gothenburg protocol, a 5% emission reduction of year 2005 emission levels was performed. The model itself can however calculate more stringent ambition levels. As an example, in the latest policy report by IIASA (Amann et al., 2013) the central policy scenario calculates scenarios with EU emission reductions corresponding to SO_2: 77; NOx: 65; $PM_{2.5}$: 50; NH_3: 27; and NMVOC: 54 per cent respectively; relative to 2005.

Aspects not covered during the course of this project

In this project Russian capacity in GAINS modelling and EMEP/MSC-W modelling as well as updated the GAINS Russia model was built so that it became functional for Russian domestic analysis of air pollution policies, mainly related to emissions of SO_2, NOx, and $PM_{2.5}$. However, the project did not explicitly cover aspects such as greenhouse gases, ozone or black carbon. The GAINS model concept is however adapted to these types of analysis (Heyes et al., 2011; Amann et al., 2008 & 2004). These aspects are all options for future adaptations of the GAINS Russia model and future Russian analysis. Furthermore, the Nordic Council of Ministers is today financing a project on black carbon emission inventories in the Russian Federation. Results from this project should prove useful in a potential GAINS Russia model research on black carbon emission abatement in the Russian Federation.

5 Conclusions and recommendations

The main results from this project were that the GAINS Russia model was updated, and that EMEP/MSC-W modelling capacity was established in the Russian Federation. The Russian project partners can now analyse impacts of different air pollution policy ambition levels and illustrate potential environmental impacts in Russian regions for communication with Russian authorities and international organizations. Intra-regional impacts can further motivate regional authorities to work together with federal authorities in order to reduce harmful effects of air pollution within the Russian Federation.

Continuous emission inventories for the regions in the GAINS Russia will be important in the future as a means to check model results with official statistics. Based on emission inventories and GAINS Russia emissions scenarios, EMEP/MSC-W model long-range pollutants transport and source-receptor calculations can also in the future be performed by the Russian Federation for topic specific analysis. Corresponding to the continued efforts is the large need for more efforts to collect relevant input data for the regions in the GAINS Russia model. In this project, it was possible to collect statistical data mainly for the NWFD region, but in order to perform a full scale analysis with the GAINS Russia model, statistical data for the other regions are needed as well.

Following a complete national data set for the entire Russian Federation in GAINS Russia is the development of emission scenarios and analysis of these, which is the central purpose of the GAINS modelling concept. The development of scenarios most often requires quantified input data for future years, which have been difficult to come by in this project. More efforts in this respect from the Russian perspective would definitely be recommended.

The GAINS Russia model could after the collection of a complete data set for Russia be further developed so that all the features available in the GAINS Europe model are available also in the Russian version. Of highest concern here is the possibility to calculate Black Carbon emissions, and to analyse impacts of ozone. Another potential development pathway could be the development of a GAINS Russia model that could calculate heavy metal emissions in the Russian Federation.

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GAINS models online

GAINS Europe

http://gains.iiasa.ac.at/gains/EUN/index.login?logout=1

GAINS Russia

http://gains.iiasa.ac.at/gains/RUN/index.login?logout=1

Appendix 1

The regions of Russia in the old GAINS Russia

Old GAINS Russia regions and consistency with the administrative division of Russia at the time.

RAINS region abbreviation	Oblast' Name (capital, if differ from Oblast' name)
ALTA	Altayskiy (Barnaul)***, Altay (Gorno-Altaysk)*
AMUR	Amurskaya (Blagoveshchensk)
BURT	Buryatiya (Ulan-Ude)*
CHIT	Chitinskaya, Aginskiy Buryatskiy (Aginskoye)**
IRKT	Irkutskaya, Ust'-Ordynskiy Buryatskiy (Ust'-Ordynskiy)**
KALI	Kaliningradskaya
KAMT	Kamchatskaya (Petropavlovsk-Kamchatskiy), Koryakskiy (Palana)**
KEME	Kemerovskaya
KHAB	Khabarovskiy***, Evreyskaya(Birobijan)*****
KOLK	Murmanskaya (Kola), Karelia*
KRAS	Krasnoyarskiy***, Taymyrskiy (Dudinka)**, Evenkiyskiy (Tura)**, Khakasiya (Abakan)*
MGDN	Magadanskaya, Chukotskiy (Anadyr')**
NOVO	Novosibirskaya
OMSK	Omskaya
PRIM	Primorskiy (Vladivostok)***
REMR	Remaining Russia within EMEP (roughly)
SAHL	Sakhalinskaya (Yuzhno-Sakhalinsk)
SPET	St.Petersburg, Leningradskaya (St.Petersburg), Novgorodskaya, Pskovskaya
TOMK	Tomskaya
TUMN	Tyumenskaya, Khanty-Mansiyskiy**, Yamalo-Nenetskiy (Salekhard)**
TUVA	Tyva (Kyzyl)*
URAL	Kirovskaya, Permskaya, Komi(part) (Syktyvkar)*, Komi-Permyaki (Kudymkar)**, Udmurtia (Izhevsk)*, Tataria (Kazan)*, Bashkiria (Ufa)*, Orenburgskaya(part), Samarskaya, Chelabinskaya(part), Sverdlovskaya(part)
URAR	Komi (part) (Syktyvkar)*, Orenburgskaya(part), Chelabinskaya(part), Sverdlovskaya(part), Kurganskaya (whole)
YAKT	Sakha (Yakutsk)*

Source: Popov, 2002

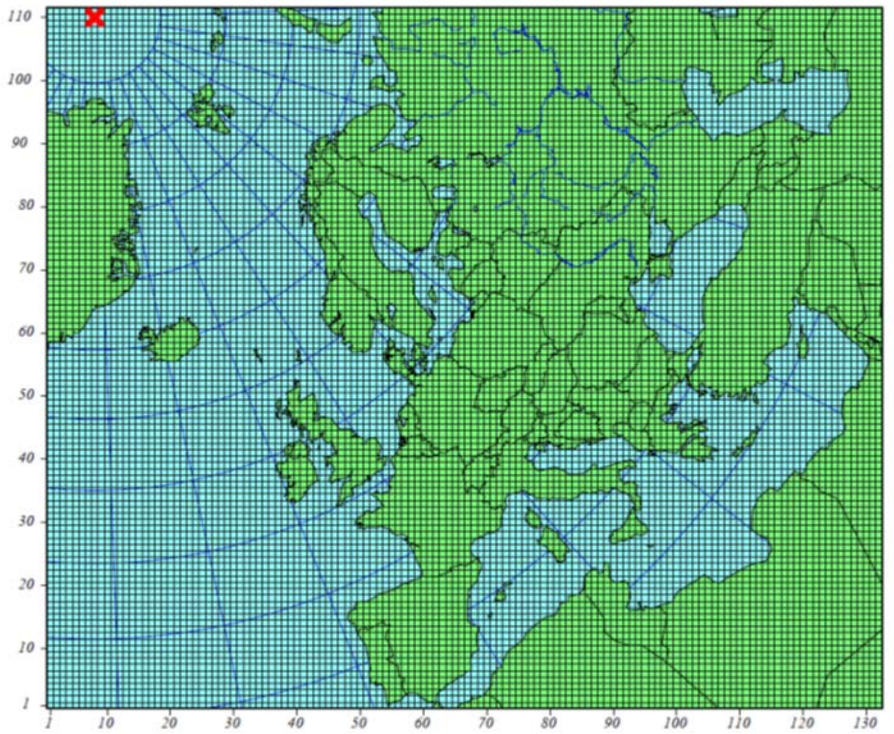
1 As usual administrative subject is "oblast", except of marked one:

*	Republic
**	Autonomous okrug
***	Kray
****	Autonomous Oblast'

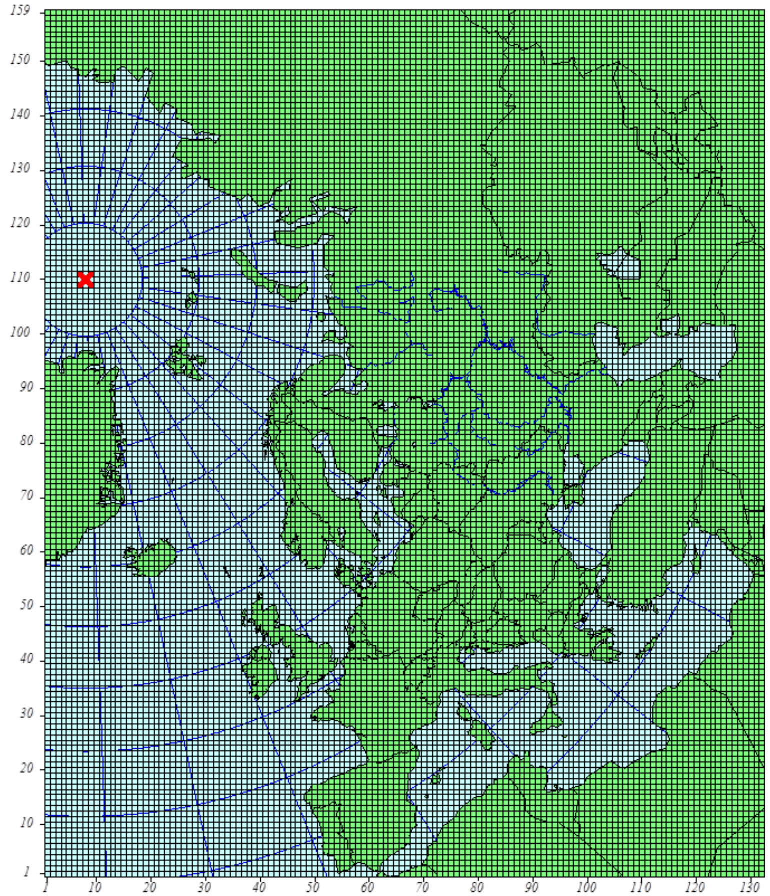
2 If name are absent then the name of the capital is parent to that of administrative subject

Appendix 2

EMEP grid domains



EMEP non-extended grid domain



EMEP extended grid domain

Appendix 3

2008 blame matrices for federal districts of the Russian Federation

Oxidised sulphur deposition, 100 Mg of S Emitters → Receptors↓

Region	CFD	LMR	NCD	NWD	SFD	VFD
CFD	701.51	179.43	12.72	72.48	65.05	131.74
LMR	61.63	131.63	1.02	5.91	3.84	9.25
NCD	8.30	2.25	215.94	1.08	42.86	9.69
NWD	264.25	108.90	6.92	702.64	32.16	198.53
SFD	56.35	11.42	59.62	5.58	299.57	60.39
VFD	337.42	105.72	17.28	62.82	112.51	1456.25

Oxidised nitrogen deposition, 100 Mg of N Emitters →Receptors ↓

Region	CFD	LMR	NCD	NWD	SFD	VFD
CFD	480.81	246.44	19.20	86.93	75.79	149.58
LMR	43.99	59.41	1.53	7.67	4.50	9.87
NCD	12.44	5.96	237.04	2.50	63.97	13.49
NWD	296.42	211.78	8.78	444.89	34.43	222.84
SFD	88.64	36.23	90.80	12.76	267.75	87.97
VFD	369.01	203.39	23.03	83.19	122.81	1063.47

Reduced nitrogen deposition, 100 Mg of N Emitters→ Receptors ↓

Region	CFD	LMR	NCD	NWD	SFD	VFD
CFD	576.45	89.00	8.12	23.75	37.28	74.72
LMR	32.75	98.96	0.62	1.30	1.88	4.09
NCD	3.96	0.69	251.16	0.38	31.58	5.02
NWD	124.71	38.30	4.07	266.26	16.31	124.44
SFD	33.94	2.69	45.58	1.29	267.73	27.61
VFD	169.46	33.35	12.51	18.34	67.00	1197.79

Appendix 4

2008 country-to-country blame matrix for oxidised sulphur deposition, ton

	KARE	LENI	MURM	VOLO	ARKH	KALI	EE	PL	DE	FI	BY	KZ	SE	UA	TR	PSKO	NOVG	NO	Rest part of EMEP
KARE	8870	1657	2711	821	1846	39	1763	2592	551	1400	654	361	237	2600	229	43	23	73	14589
LENI	594	6269	496	632	508	31	4196	1910	450	536	653	183	95	2207	148	72	43	29	11874
MURM	1237	208	17375	210	1481	12	369	1127	373	789	197	189	232	907	74	10	5	77	7093
VOLO	433	863	542	6941	1038	27	706	2035	381	312	563	1168	76	4198	648	43	31	27	23496
ARKH	2407	1243	3713	2423	17137	55	1495	3832	737	1194	796	1694	262	5645	996	53	29	99	34303
KALI	8	13	21	4	4	447	36	2329	325	32	66	8	23	409	16	2	0	7	2620
EE	99	217	168	50	62	38	2662	2228	527	378	355	45	100	1496	49	35	4	27	9434
PL	120	149	257	59	86	560	521	190332	16137	339	1469	122	294	14955	590	23	4	117	73637
DE	101	97	146	40	37	82	247	18136	105850	194	465	77	202	2550	110	12	3	151	119303
FI	4002	1228	5004	405	1016	97	2957	6204	1725	10406	1030	261	1226	4722	209	66	20	286	31015
BY	221	268	381	147	195	192	541	19093	2032	365	9986	497	122	26810	1894	91	9	37	33141
KZ	43	56	77	109	123	10	123	1615	300	60	254	37174	15	11102	4290	7	2	6	42170
SE	813	398	1776	227	490	103	923	7327	5729	2261	524	155	4520	2608	60	26	8	1093	65225
UA	248	247	496	240	313	124	463	34482	3443	388	3240	2960	122	248255	17683	40	8	40	156900
TR	31	45	56	63	79	14	41	2243	535	41	248	1356	18	9872	343876	7	2	9	228988
PSKO	148	393	214	104	116	38	1694	1987	380	218	1507	120	61	2750	186	474	13	21	8113
NOVG	248	1001	293	346	284	26	681	1338	339	210	670	160	48	1995	158	104	167	15	8244
NO	331	102	4635	68	244	34	177	2416	2696	479	151	63	472	788	22	7	2	2085	45159

Appendix 5

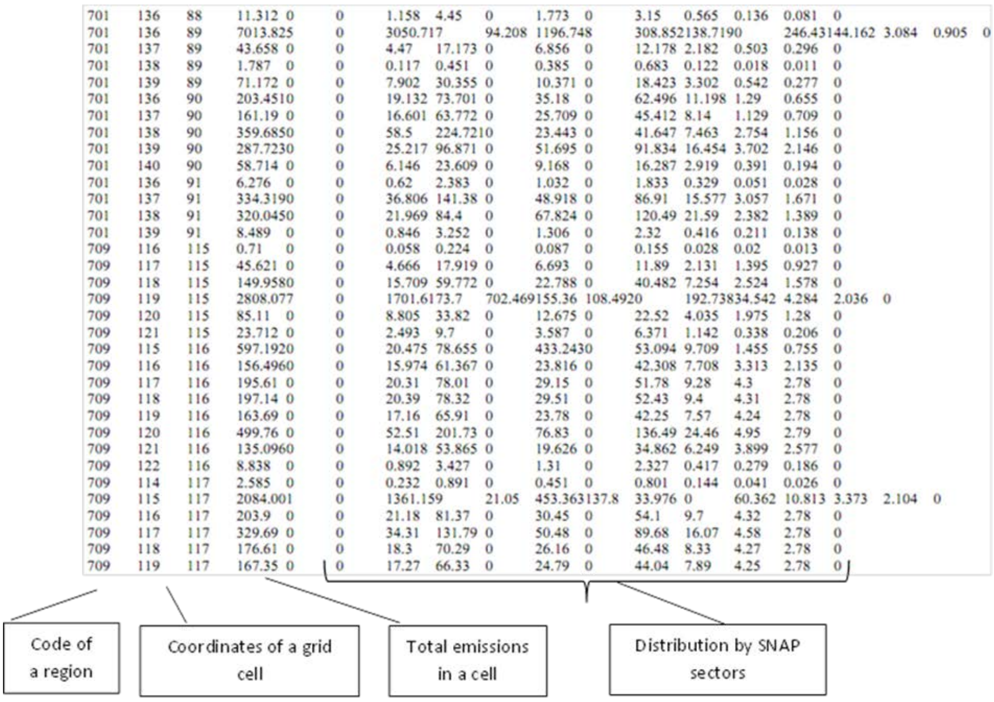
Extracts from a fraction file and an emission file

Fraction file

YX_GIS	code_fed_okruga	frac_new	X_mod	Y_mod
63067	708	1	102	74
63068	708	1	103	74
74100	701	1	135	85
75067	708	1	102	86
75100	701	1	135	86
77073	704	0.16	108	88
77073	708	0.84	108	88
77074	704	1	109	88
77085	704	1	120	88
77086	704	1	121	88
78071	704	0.476	106	89
78071	708	0.524	106	89
78072	704	0.836	107	89
78072	708	0.164	107	89
78073	704	0.9	108	89
78073	708	0.1	108	89
78074	704	1	109	89
79070	708	1	105	90
79071	704	0.458	106	90
79071	708	0.542	106	90
79072	704	1	107	90
80070	708	1	105	91
80071	704	0.56	106	91
80071	708	0.44	106	91
80072	704	1	107	91
80103	701	1	138	91
80104	701	0.96	139	91
80104	702	0.04	139	91
80105	701	0.337	140	91

YX_GIS – grid cell ID in GIS; code_fed_okruga – code of a region; frac_new – fraction of a region in a grid cell; X_mod, Y_mod – coordinates of a grid cell

Emissions file

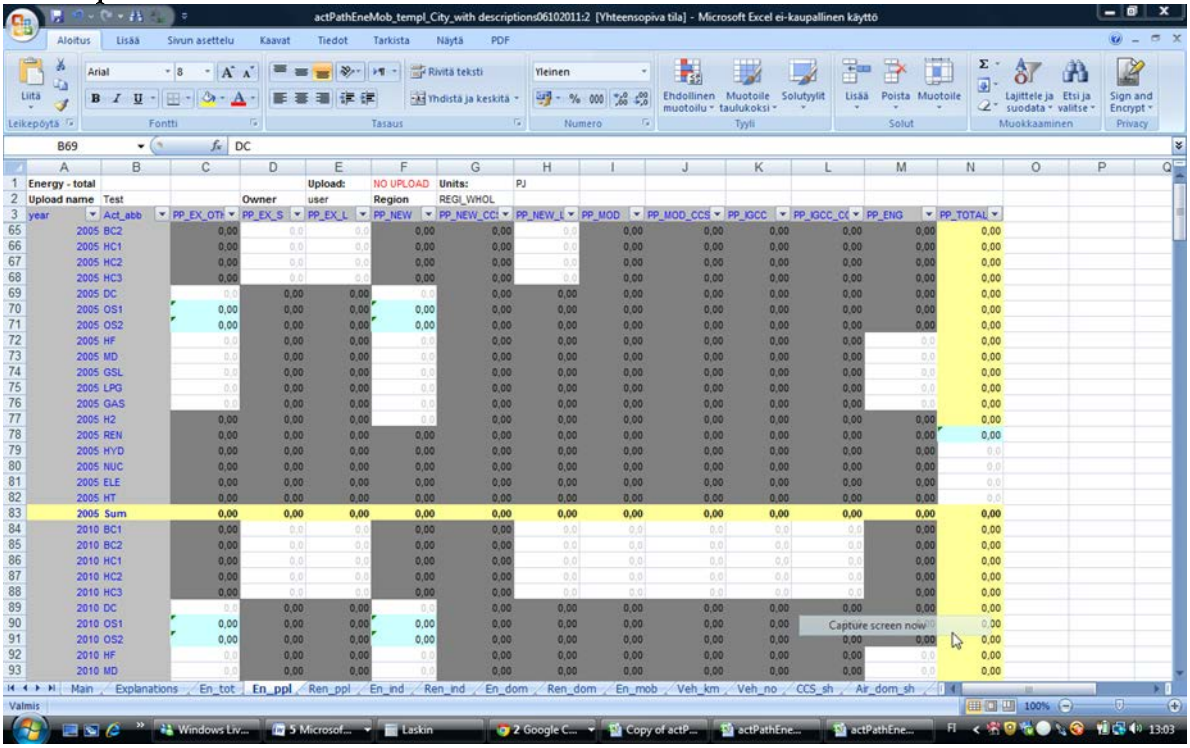


```
701 136 88  11.312 0  0 1.158 4.45 0 1.773 0 3.15 0.565 0.136 0.081 0
701 136 89  7013.825  0 3050.717 94.208 1196.748 308.852138.7190 246.43144.162 3.084 0.905 0
701 137 89  43.658 0  0 4.47 17.173 0 6.856 0 12.178 2.182 0.503 0.296 0
701 138 89  1.787 0   0 0.117 0.451 0 0.385 0 0.683 0.122 0.018 0.011 0
701 139 89  71.172 0  0 7.902 30.355 0 10.371 0 18.423 3.302 0.542 0.277 0
701 136 90  203.4510  0 19.132 73.701 0 35.18 0 62.496 11.198 1.29 0.655 0
701 137 90  161.19 0  0 16.601 63.772 0 25.709 0 45.412 8.14 1.129 0.709 0
701 138 90  359.6850  0 58.5 224.7210 23.443 0 41.647 7.463 2.754 1.156 0
701 139 90  287.7230  0 25.217 96.871 0 51.695 0 91.834 16.454 3.702 2.146 0
701 140 90  58.714 0  0 6.146 23.609 0 9.168 0 16.287 2.919 0.391 0.194 0
701 136 91  6.276 0   0 0.62 2.383 0 1.032 0 1.833 0.329 0.051 0.028 0
701 137 91  334.3190  0 36.806 141.38 0 48.918 0 86.91 15.577 3.057 1.671 0
701 138 91  320.0450  0 21.969 84.4 0 67.824 0 120.49 21.59 2.382 1.389 0
701 139 91  8.489 0   0 0.846 3.252 0 1.306 0 2.32 0.416 0.211 0.138 0
709 116 115 0.71 0    0 0.058 0.224 0 0.087 0 0.155 0.028 0.02 0.013 0
709 117 115 45.621 0  0 4.666 17.919 0 6.693 0 11.89 2.131 1.395 0.927 0
709 118 115 149.9580  0 15.709 59.772 0 22.788 0 40.482 7.254 2.524 1.578 0
709 119 115 2808.077  0 1701.6173.7 702.469155.36 108.4920 192.73834.542 4.284 2.036 0
709 120 115 85.11 0   0 8.805 33.82 0 12.675 0 22.52 4.035 1.975 1.28 0
709 121 115 23.712 0  0 2.493 9.7 0 3.587 0 6.371 1.142 0.338 0.206 0
709 115 116 597.1920  0 20.475 78.655 0 433.2430 53.094 9.709 1.455 0.755 0
709 116 116 156.4960  0 15.974 61.367 0 23.816 0 42.308 7.708 3.313 2.135 0
709 117 116 195.61 0  0 20.31 78.01 0 29.15 0 51.78 9.28 4.3 2.78 0
709 118 116 197.14 0  0 20.39 78.32 0 29.51 0 52.43 9.4 4.31 2.78 0
709 119 116 163.69 0  0 17.16 65.91 0 23.78 0 42.25 7.57 4.24 2.78 0
709 120 116 499.76 0  0 52.51 201.73 0 76.83 0 136.49 24.46 4.95 2.79 0
709 121 116 135.0960  0 14.018 53.865 0 19.626 0 34.862 6.249 3.899 2.577 0
709 122 116 8.838 0   0 0.892 3.427 0 1.31 0 2.327 0.417 0.279 0.186 0
709 114 117 2.585 0   0 0.232 0.891 0 0.451 0 0.801 0.144 0.041 0.026 0
709 115 117 2084.001  0 1361.159 21.05 453.363137.8 33.976 0 60.362 10.813 3.373 2.104 0
709 116 117 203.9 0   0 21.18 81.37 0 30.45 0 54.1 9.7 4.32 2.78 0
709 117 117 329.69 0  0 34.31 131.79 0 50.48 0 89.68 16.07 4.58 2.78 0
709 118 117 176.61 0  0 18.3 70.29 0 26.16 0 46.48 8.33 4.27 2.78 0
709 119 117 167.35 0  0 17.27 66.33 0 24.79 0 44.04 7.89 4.25 2.78 0
```

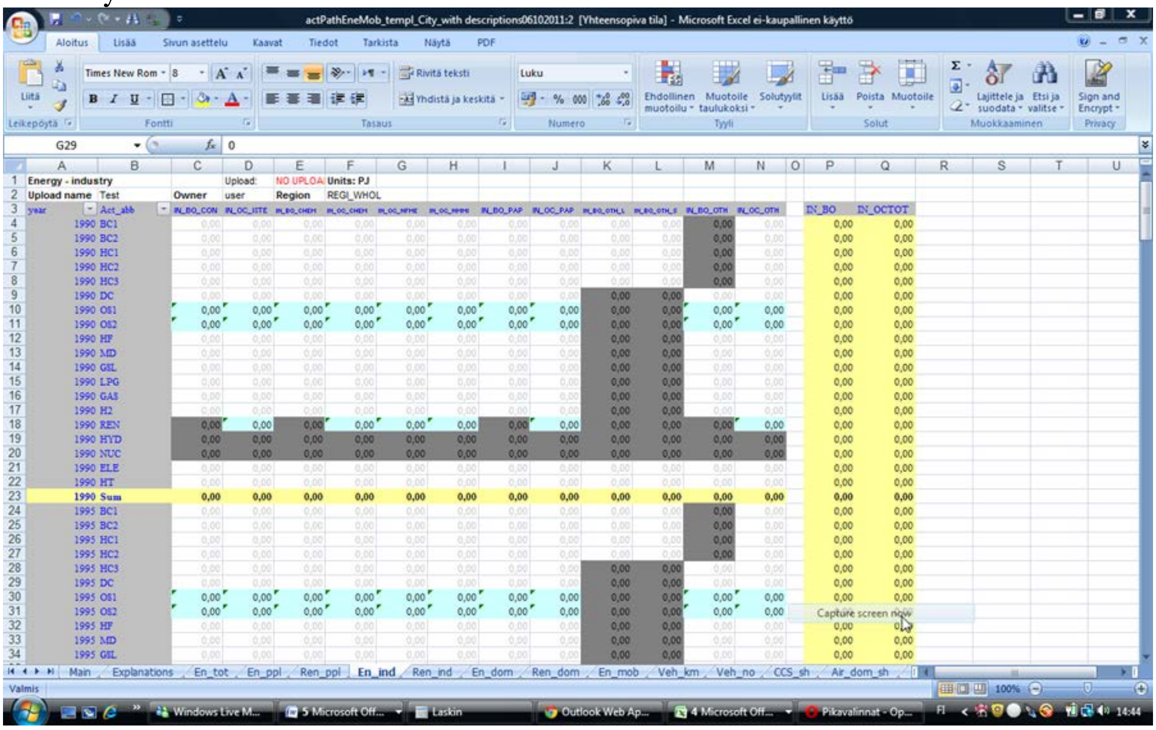
Appendix 6

Examples of new GAINS template structure developed in 2011

Power plants



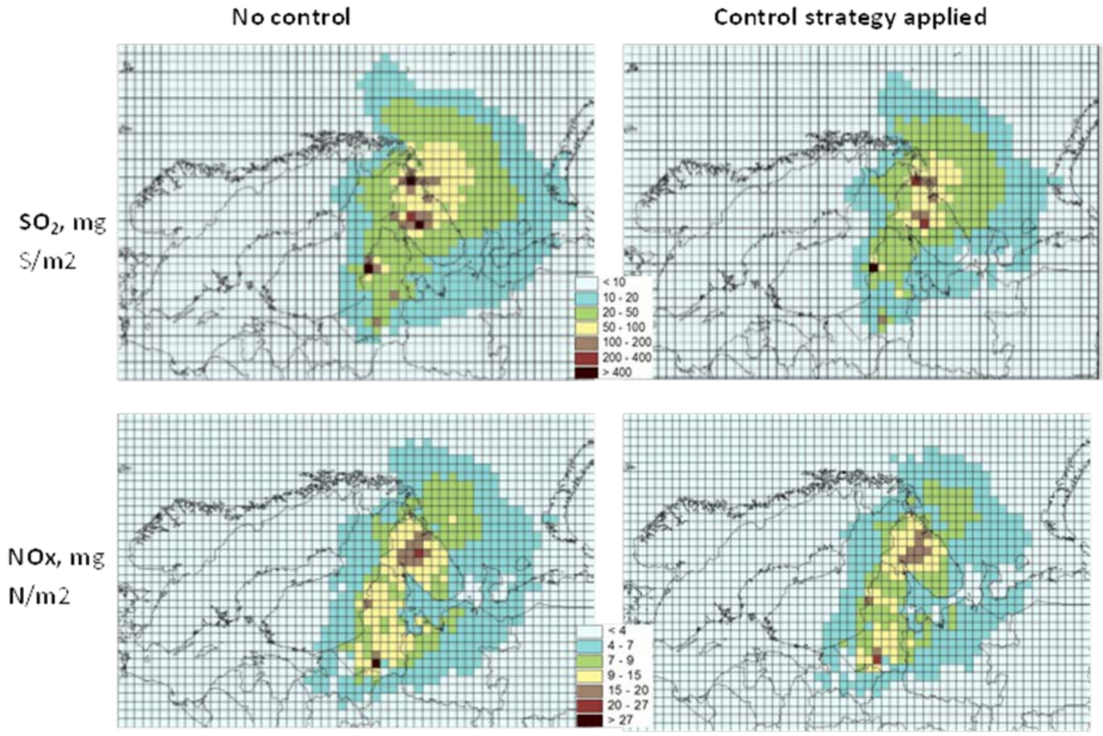
Industry sector



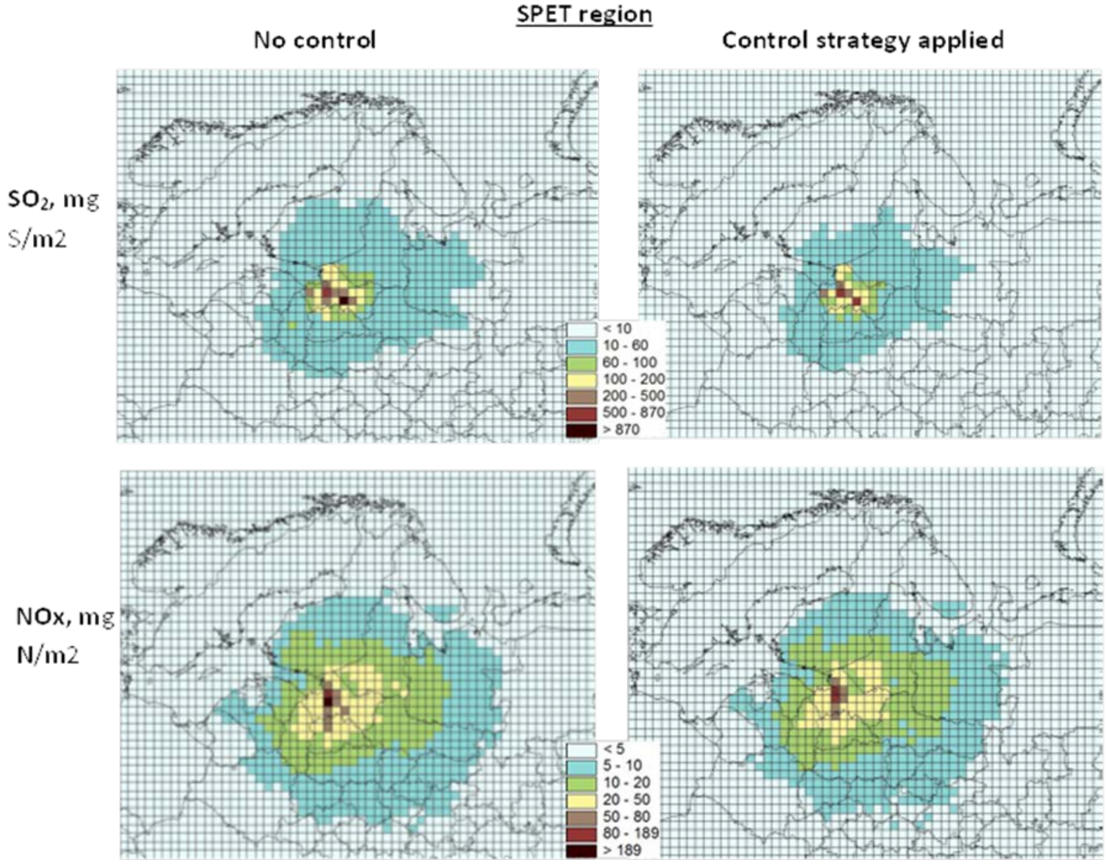
Appendix 7

NO_x and SO_2 deposition from emissions in KOLK and SPET regions, 2005

KOLK region



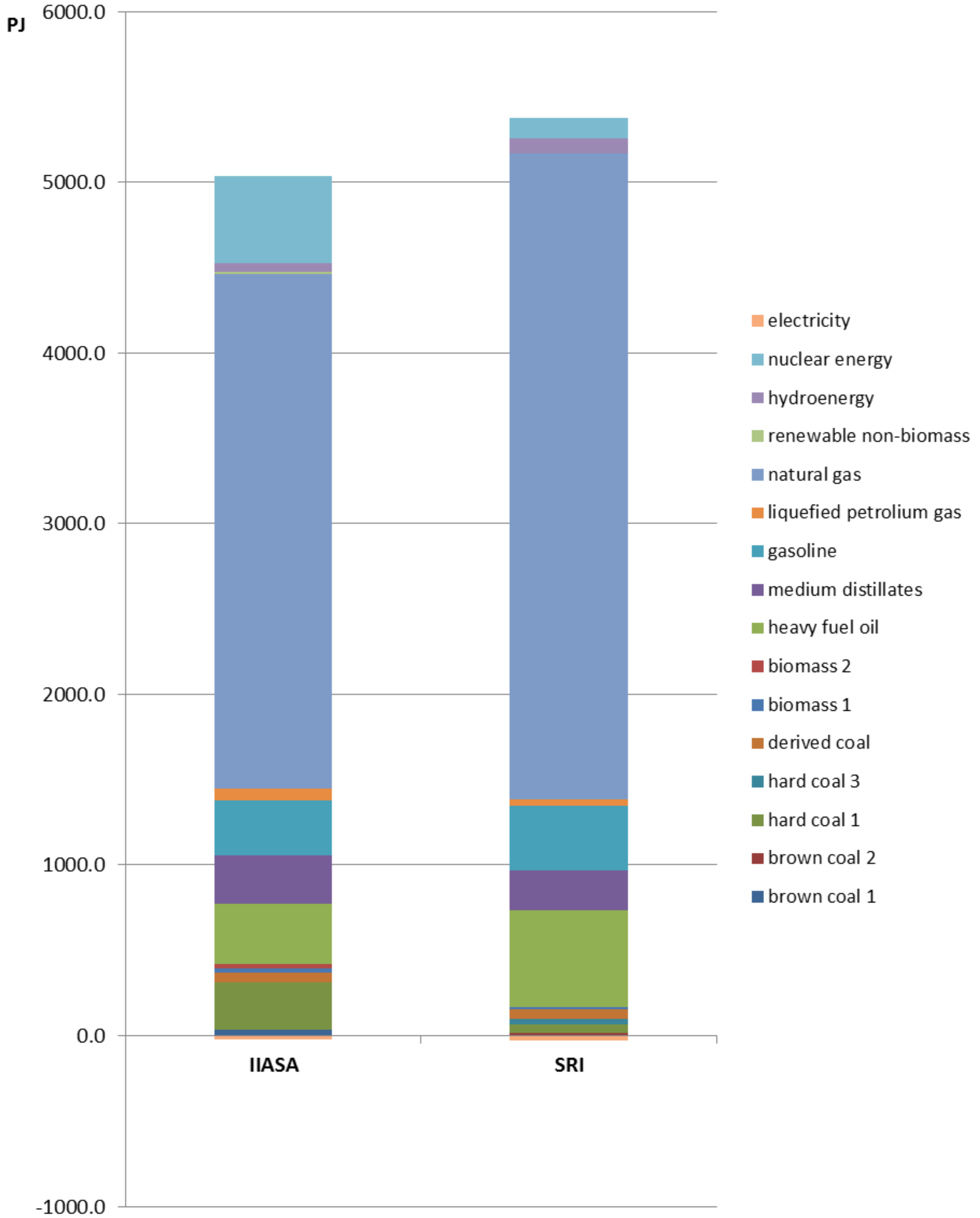
SPET region



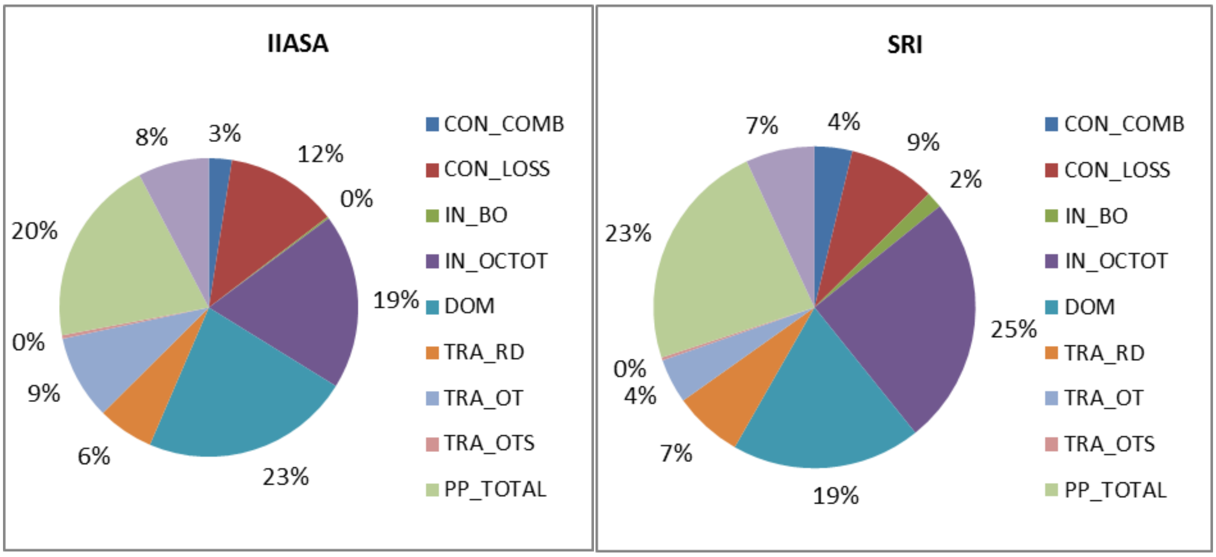
Appendix 8

Summary of activity data sets for the Volga Federal District, year 2010

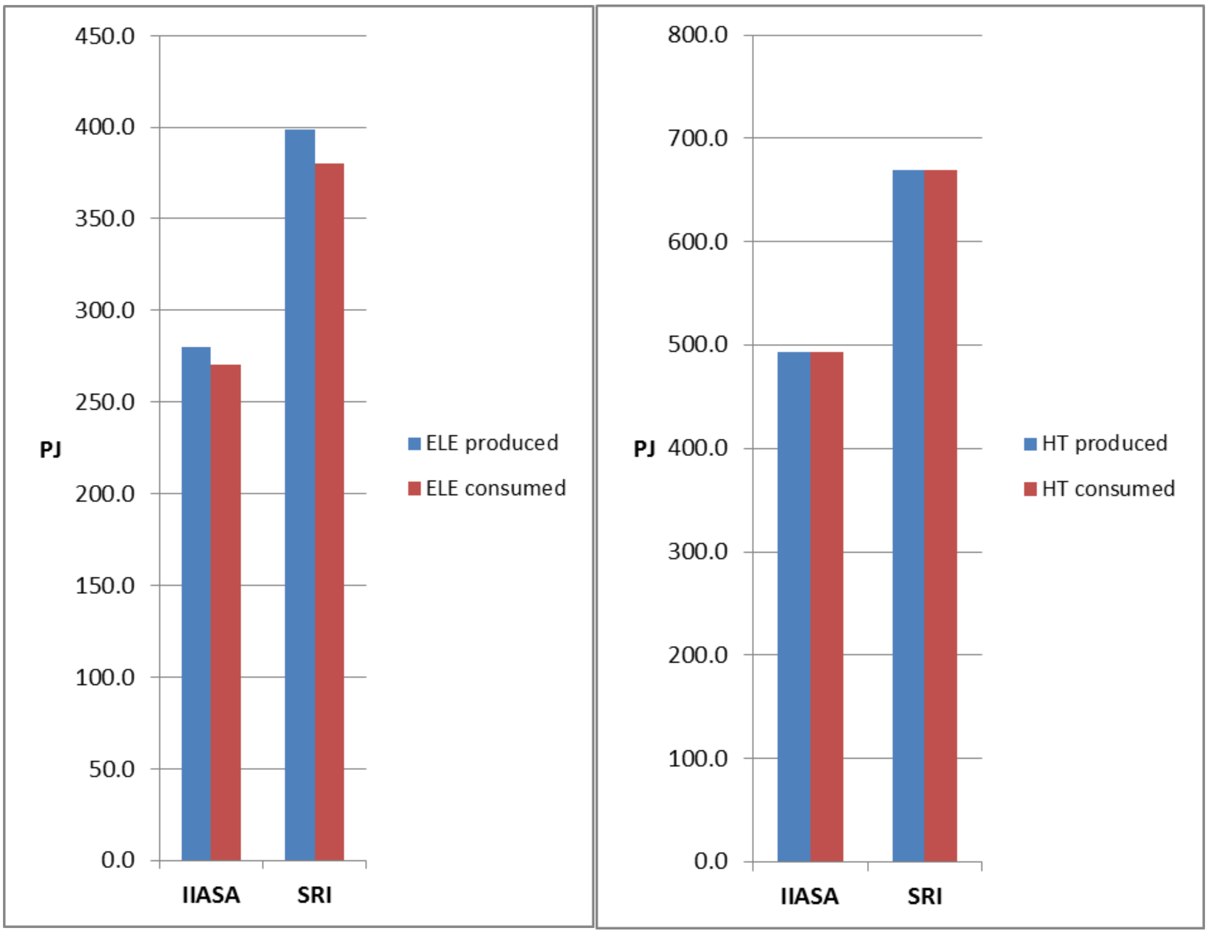
Energy consumption by fuels



Energy consumption by sectors



Production and consumption of electricity and heat



Appendix 9

Emissions by regions: National emission inventory vs. the GAINS Russia, kt, 2010

Region	GAINS Russia		National emission inventory
	IIASA	SRI	
SO_2			
North-Western FD	650	616	603
Central FD	232	186	172
-Other Central	530	-	133
-Larger Moscow region	120	-	39
Volga FD	507	617	359
Southern FD	235	-	111
North Caucasian FD	161	-	12
TOTAL European part	1785	-	1257
NO_x			
North-Western FD	348	-	317
Central FD	979	-	727
-Other Central	798	-	-
-Larger Moscow region	181	-	-
Volga FD	762	743	627
Southern FD	353	-	215
North Caucasian FD	242	-	189
TOTAL European part	2684	-	2075
$PM_{2.5}$			
North-Western FD	154	-	-
Central FD	243	-	-
-Other Central	202	-	-
-Larger Moscow region	41	-	-
Volga FD	214	26	-
Southern FD	96	-	-
North Caucasian FD	60	-	-
TOTAL European part	767	-	-